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THE DEVELOPMENT OF THE EARTH'S CRUST AND THE NATURE OF GRANITE[1]

by

V. V. Tikhomirov

Because acidic rocks are not known in meteorites, the author believes that all granite has been formed during a certain stage in the earth's development.

This paper also presents the view that granitization as a result of metasomatism may take place only in elevated zones, but in depressed regions metasomatism leads to basification of sial, to the point of transformation into rocks of completely ultrabasic composition. In the course of the earth's development, the existence of the sial layer and granites are temporary phenomena.

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Among the massive crystalline rocks constituting the earth's crust, granites and granodiorites are broadly distributed and petrographically classed as intrusives of acidic composition. Volcanic products of acidic magma are also significant as extrusive rocks. Moreover, among rocks of metamorphic origin, there are numerous types whose composition is similar to that of granite. These facts indicate the importance of rocks rich in silica in the earth's crust and have given rise to century-long polemics on the origin of granite. At the present there are various concepts on the subject, many of which are basically divergent.

The concepts concerning the nature of granite may be divided into two principal types. The first group considers granite to be of magmatic origin and the other considers it to be metamorphic in origin. The advocates of the magmatic theory differ about the details. The following concepts are widely known: a) acidic magma is one of the products of crystallization differentiation from a uniform magma (N. Bowen, P. Niggli, and others); b) in the earth there can be three independent types of magma: peridotitic, basaltic, and granitic (A. Holmes); c) there are two original types of magma, basic and acidic (F. Yu. Levinson-Lessing); d) granitic magma was formed as a result of the melting of sedimentary rocks (M. Lyuzhon and others).

The first three hypotheses are based on the assumption that the granitic magma is juvenile, while the advocates of the last viewpoint believe that acidic magma is the product of melting of other rocks and is of palingenetic origin. Recently, another idea became broadly known -- that metamorphism is important in this problem and that many massive crystalline rocks, including granite, resulted from complicated metasomatic processes.

This point of view comes close to the concept of palingenesis, for metamorphism in its extreme form (ultrametamorphism)

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[1]The problems discussed in V. V. Tikhomirov's article are among the most complicated problems in geology and their solution requires information which is still inadequately developed geologically and physically.

The author's interpretation of the history of the earth's sial layer is not accompanied by data on the material balance of transitions from the original ultrabasic magma to granitic magma and back to peridotitic magma. The author fails to take into account that geophysical data on the composition of the earth's crust indicate the variations of density in various spheres but not the petrographic composition of the rock layers.

The solution of the problems discussed in this article requires close cooperation of geologists, geophysicists, and other experimenters in the field of petrogeny and in the study of the physical properties of rocks under various conditions. -- Editor.

means melting of originally sedimentary material.

The known points of view on the origin of granite are reviewed in works by B.M. Kupletskiy [15], P. Niggli [18], G.D. Afanasyev [2], B.S. Sobolev [24], and others, and there is, therefore, no need to repeat them. It must be emphasized, however, that the origin of granite is still a subject of polemics and facts not taken into account in previous works may give rise to new ideas.

In order to come closer to a solution of the problem, one must first limit the number of possible types of origin. As one avenue of research, we recommend that the facts available on the science of cosmic bodies be taken into account, together with data derived from the study of the earth's crust. It is known that all the chemical elements discovered in the earth occur in other planets of the solar system [11]. It would seem that various combinations of these elements should lead to the formation of magmatic rocks identical to those known from the earth's crust. The study of the petrographic composition of meteorites reveals, however, that all the known rock meteorites are of ultrabasic composition.

No meteorites of acidic composition have been found. In a few cases, tectites having a more than 90 percent SiO_2 content have been found. However, as noticed by Ye. L. Krinov [12], the ratios of certain elements composing tectites and their ages, as determined by the argon method, indicates that tectites are of earthly and not of cosmic origin. Thus, rock meteorites, which according to V.G. Fesenkov [27] are most probably the product of disintegration of a large planet, consist completely or mostly of basic rocks. Geophysical data indicate that 99 percent of the volume of the internal part of our planet consists of peridotitic or metallic material. This statement is fully consistent with the results of the study of deep faults that are accompanied by extrusions of ultrabasic and basic magma.

The above considerations permit one to believe that juvenile magma formed in the earth and other planets of the same original material is close to ultrabasic in composition, whether it was formed as a result of the melting of meteoritic dust or from condensation of a gaseous nebula. In the course of consolidation, various components of planets are undoubtedly redistributed and this leads to the formation of various spheres in which one or another chemical element predominates. However, it appears that the conditions necessary for the formation of an acidic magma do not exist in any of the spheres. This conclusion can be drawn logically, for should molten silicates of acidic composition exist in cosmic bodies, some meteorites of the same composition would be found among those striking the earth. Since no meteorites of acidic composition are known, there is good reason to assume that the genesis of granite requires specific conditions absent in the majority of planets, but inherent to the earth.

Modern scientific views permit the assumption that the processes at depths having the same density in cosmic bodies should not differ in principle from those taking place in other planets. Therefore, the conditions leading to genesis of granite in our planet do not apply to its deeper layers but to its crust, and these conditions may be found in a particular balance existing in the physicochemical environment in the earth's crust. These considerations justify rejection of the hypothesis that postulates the existence of a juvenile acidic (granitic) magma in deep spheres of the earth or postulates that such a magma may emerge as a result of crystallization differentiation. This conclusion limits the number of possible types of origin of granite and consequently brings us closer to the solution of the problem.

It must be noted that many petrologists have recently rejected the concept of the juvenile nature of granitic magma, each following different paths and recognizing that the original material of granites is the sial layer of the earth.

In conformity with modern data on the composition of our planet, summarized in the works of V.A. Magnitsky [17], P.N. Kropotkin [13], and others, the earth is not uniform but consists of a number of spheres of different geophysical properties. The external sphere, called the crust, consists in its upper part of a sedimentary mantle, both on continents and under oceans, and of granites known only on continents. Further below, at the base of the earth's crust, there is a continuous basaltic layer. This layer, the lower part of the sial, is separated from the deeper peridotitic layer by a clear boundary -- the Mohorovicic discontinuity.

There are good reasons to believe that the sial layer was formed at a certain stage of the earth's development and that the surface of the planet originally consisted completely of ultrabasic rocks. When and under what conditions was the sial layer formed?

Let us review how and of what the sial could be formed, starting with the sedimentary mantle of the continents.

Because the relatively light compounds of silica and alumina prevail in the earth's crust, many geologists were inclined to believe that the sedimentary mantle is a product of decomposition of some kind of an original granitoid crust. However, further studies on the subject disclosed that there is no basis for this hypothesis and that the known sedimentary mantle (except for organic sediments) may have been derived from ultrabasic rocks which probably made up the original crust.

The weathering of basic and ultrabasic rocks, as observed in our time, includes a complex of physical and chemical processes. Thereby, the original substances become decomposed and differentiated; some minerals disappear, others emerge, and the process as a whole leads toward the formation of sedimentary layers rich in silica, alumina, and carbonates. It appears that the formation of these sedimentary rocks does not require original material of the same chemical composition as the products of its weathering. For example, according to A.A. Polkanov [21], the weathering of basic rocks in a humid, warm climate produces solutions of alkaline silicates and colloidal silica; carbonates and bicarbonates of calcium, magnesium, and iron; sodium sulfate, and potassium carbonate; besides clay and sand of still undecayed minerals.

The weathering of such an ultrabasic mineral as olivine produces magnesium and iron carbonate, limonite, and silica.

Orthorhombic pyroxene, one of the most important minerals of ultrabasic rocks, produces the same final products as those of weathered olivine. I.I. Ginzburg [5], who studied the weathered crust of ultrabasic rocks in the Urals, showed that decomposition of serpentine produces opal, chalcedony, quartz, and chrysoprase along with some other minerals, and that the weathering of monoclinic pyroxene yields aluminum hydroxide gibbsite.

As we know, the complete decomposition of augite, amphiboles, plagioclase, and some other minerals constituting basic rocks produces the same final products as does the weathering of granites.

It is important to note that a substantially higher quartz content in sedimentary rocks relative to that in basic rocks may easily be explained by the fact that the decomposition of all the silicates leads to the formation of free silica, which accumulates in the form of opal, chalcedony, and other modified forms of silica. At the same time, rich iron-magnesium solutions seep into deep zones of the earth's crust and perhaps reach the peridotitic layer enroute, causing some alterations in the chemical composition of porous rocks of the ocean floor.

The oldest sedimentary rocks of the mantle, despite their high silica and alumina content, are very likely formed of the weathering product of the original crust of the earth, which had a sima composition. For instance, according to N.V. Frolova [29], the oldest Archean para-rocks in southeastern Siberia have the following composition: 54 to 57 percent SiO_2; 10 to 11 percent Al_2O_3; 12 to 13 percent FeO + Fe_2O_3; 5 to 6 percent MgO; 8 to 8.5 percent CaO; 4 percent alkaline oxides. N.V. Frolova believes that these rocks, despite an essential silica content, are formed of the weathered formations of basic magma.

N.V. Frolova [28] draws the conclusion that the original sima layer of the earth could provide all the necessary material for the formation of Archean sediments; the source of sediment supply was adequate because the chemical decomposition of basic rocks containing large amounts of iron, magnesium, and calcium silicate proceeds rapidly. In this connection, there are some peculiarities inherent in the process of weathering. Weathering, occurring at different rates under different climatic conditions, is one of the most important factors in the formation of unconsolidated terrigenous materials that constitute sedimentary rocks. For example, the rate of weathering is greatly increased in warm and humid climates and in the presence of great amounts of carbon dioxide in the air or in surface waters.

In analyzing the history of changing physiographic conditions as reflected in geologic time, it is believed that the intensity of weathering in the Precambrian was greater than during the last 600 million years. V.A. Obruchev [20] wrote that parts of the Siberian shield carry clear signs of intense chemical and physical weathering. Similar facts were mentioned by D.S. Korzhinskiy [7] in his works describing the Aldan massif. A.A. Polkanov [22] noticed that the rocks of the Baltic shield indicate the presence of large Precambrian land masses favorable for extensive weathering and sedimentary differentiation. Similar physiographic conditions existed in Archean and Proterozoic time in other regions of our planet, too.

It is known that the soils carrying circulating acids contribute to more rapid weathering of underlying rocks. But in the Archean, despite the absence of favorable conditions, weathering took place rapidly and completely because of the Archean environment. There is good reason to believe that

at that time the carbon dioxide content in the air was much higher than now. Surface plants during the last half billion years may have consumed a substantial part of it, turning it into thick layers of coal and large quantities of carbon dioxide were precipitated in the form of calcium carbonate in the seas. It is also possible that the temperature at the earth's surface in Archaean time was considerably higher than it is now.

According to an estimate by V. G. Khlopin, the amount of heat from the radioactive decay in the earth's crust was five times greater three billion years ago in the Archaean and twice as high two billion years ago than it is now. Besides, the sun's rays heated the surface of the earth to a higher temperature because of the topography of that time, when seas were relatively shallow and land was cut by numerous straits. Rocks heated to high temperatures, exposed at the surface without soil and plants, may have supplied the waters of adjacent basins with substantial heat. Thus, even without applying the hypothesis of periodic increase in the internal heat of the earth to increase the temperature at the earth's surface, one may suggest that in the Precambrian, there were adequate conditions for very extensive weathering of rocks exposed on the surface. Such weathering may have caused the accumulation of a thick mantle of sediments in regions close to the zones of weathering and apparently initiated the formation of the sial layer.

Let us now review the relation of the sedimentary mantle to granites. By studying the average chemical composition of all known sediments, it is clear that this average composition of the sediments could correspond to the original material of the molten granitic magma.

Pointing to this fact, G. D. Afanasyev [3] notes that melting of the sedimentary stratum may produce substantial amounts (15 to 20 percent) of a magma, the composition of which would be close to that of a granitic eutectic mixture.

However, palingenesis is not the only way that leads to formation of granite. Observations reveal that palingenesis may have only a subordinate significance. Recent studies indicate that there are a number of metamorphic rocks which do not differ from those which have been considered to be magmatic.

As a result of long and complicated action of various types of metamorphism on Archaean sedimentary stratum, there could undoubtedly emerge conditions under which sedimentary rocks could turn into massive crystalline formations of a granitic type.

As pointed out by N. G. Sudovikov [26], within the Archaean rocks of the Baltic shield, there are a number of localities in which the country rocks gradually pass into granite. Elsewhere, relicts identical to the country rocks occur within large granitic bodies, and they completely preserve the structure and bedding of the enclosing stratum.

N. G. Sudovikov, in describing his own observations, writes that the rocks originally differing in composition may turn into granitoids and granites as a result of sequential replacement.

The basic rocks of northern Karelia, being granitized first, turned into quartz-feldspar amphibolite and then into amphibole gneiss of granitic composition. Thereby the plagioclase gradually became less basic, its content in the rock increased, quartz emerged and gradually increased in content, pyroxene was amphibolized and amphibole gradually disappeared, turning into newly formed biotite. This process was, according to N. G. Sudovikov, a result of Na, K, and Si invasion and Fe, Mg, and Ca withdrawal.

According to D. S. Korzhinskiy, genuine granites are always formed of molten magma. At the same time, he thinks that under certain conditions granitization may sometimes result from a metasomatic replacement of some elements by others directly in the solid state. The replacement is completed to its full extent in those rocks whose silica, alumina, iron, and other small mobile components percentagewise become close to the composition of granite. D. S. Korzhinskiy believes that granitization takes place under the influence of solutions penetrating the magma infiltrating from the sub-mantle. Thereby, if the temperature of the solution is high, the contact zone melts and the magmatic replacement takes place in a similar way to the metasomatic one. D. S. Korzhinskiy [10] believes the currents penetrating the magma, causing granitization in the enclosing rocks, metamorphose those layers through which they pass. Potassium and sodium, as a general rule, are fully mobile during magmatic granitization and metasomatism; the mineral composition of newly-formed rocks is determined by the chemical potential of these elements in the system of the given process.

On the basis of the above facts and considerations, we may consider the overwhelming majority of Precambrian granites to be of secondary metamorphic origin and formed as a result of metasomatism or magmatic replacement. The young granites,

however, about whose intrusive nature there is no doubt in the majority of cases, may be considered a result of melting of older granites and of sedimentary rocks.

This point of view is not new. It was expressed in different versions by I. Sederholm, H. Reed, H. Backlund, R. Rastall, and a number of other foreign investigators.

As noted by Yu. A. Kuznetsov [14], concepts concerning various transformers differ in detail, for example, in explanation of migration of rock-forming substances during granitization. Some ascribe this effect to the infiltration of fluid and gaseous solutions; others suggest diffusion of ions in solid matter, and still others adhere to diffusion of ions in a fluid, immobile environment. But all of them consider metasomatism to be the decisive factor.

In recent years, both the theory of metamorphic origin of granite and that concerning the melting of the sial layer have gained a large number of adherents among Soviet geologists. Nevertheless, nearly every author suggests his own version of the origin of granite. Thus, besides those of G. D. Afanasyev, D.S. Korzhinskiy, P.N. Kropotkin, N. G. Sudovikov, and some others, we may refer to the concepts of V.A. Nikolayev [19], who assumes that granitoid magma is a result of periodic melting of the sial layer, during which emanations rise from the depths.

L.V. Pustovalov [23] attaches great importance to the metamorphism of sedimentary rocks and points to the fact that deeply metamorphosed sedimentary rocks become very similar to magmatic rocks and, in the final stage (ultrametamorphism), melt and form a secondary magma. Without mentioning all the points of view expressed by Soviet geologists, and without analyzing the details, let us merely stress that a combined application of the hypotheses on metasomatism and melting permits one to explain a number of complicated problems which could not be solved by magmatism. Particularly, the space problem of large batholiths is easily solved. The assumption of the periodic appearance of new centers of melting in various sial zones permits one to understand the cause of variations in extrusive rocks. In establishing a theoretical concept on the origin of granite, one has always to take into account an important fact -- that granites are known only in elevated zones. They are part of the continental cycle and are exposed in the core of anticlinal folds. Even within present continents, intrusives in synclinal structures are never of granitoid composition, but are, as a general rule, basic or ultrabasic. This empirically established fact apparently indicates the existence of conditions favorable for granitization only in elevated zones.

All the above facts and logical considerations lead to the conclusion that the sial layer, formed at a certain stage of the earth's development, was a requisite for the formation of granitoid rocks. If so, why were granites not formed in other planets in a similar way?

Similar physiographic and chemical conditions leading to the sial formation might appear in those cosmic bodies whose composition is close to that of the earth. Thus, the formation of the sial layer is greatly aided by an atmosphere similar to that of the earth and the surface relief and topographic contrast, periodically juvenilized by tectonic movements. However, within the solar system, the presence of conditions similar but still far from identical to those of the earth may be assumed only on Mars and Venus. For example, on Mars the topographic contrast appears to be absent at the present time, and consequently at the present stage of development of this planet, no tectonic movements of consequence occur there. Therefore, despite the presence of water vapor and great amounts of carbon dioxide in the atmosphere of Mars, weathering involves only a thin sheet of rocks exposed on the surface of Mars. Chemical processes must take place very slowly on Mars because of the predominantly low temperatures. Therefore, even on the planets whose general features are similar to those of the earth, no favorable conditions exist for the formation of a thick sial layer or granite.

Let us assume that at a certain stage of development of a planet, its surface becomes covered by a sial layer in an initial form. Let us try, with the example of the earth, to forecast the further development of the sial layer and of newly-formed granitoids. For this purpose, let us acquaint ourselves with the characteristics of the sial layer in deep seas.

According to geophysical data, the thickness of sial in the deep parts of oceans averages about 10 kilometers, but in continents it averages 30 to 50 kilometers. Many investigators believe that geotectonic development of the earth leads to broadening of areas occupied by continents and therefore to an increase in the sial layer. However, a number of circumstances contradicting this assumption must be analyzed.

Deep-water regions which in the recent past were dry land obviously had a thick sial layer similar to that of continents. However, available data is not consistent

with this seemingly logical assumption. In the deep part of the Bering Sea, gravimetric data revealed that the thickness of the sial layer was as usual for oceans. However, logs recovered from a depth of 3,683 meters in the eastern part of the sea, according to A.P. Zhuze, had, in one of the thin beds, a fresh-water benthonic diatom of Quaternary age. This indicates that this part of the sea was even recently near a coast or at least a continental slope. It is, of course, possible that the benthonic forms were transported from land by muddy streams, but this assumption is unlikely, because the presence of this form was noticed only at a certain stratigraphic level.

The Sea of Japan has, according to geophysical data, a crust of the same thickness as that under oceans. However, the area of the Sea of Japan was, according to G.U. Lindberg [16], a land drained by the paleo-Suyfun and paleo-Amur Rivers.

According to V.V. Belousov [4], many parts of the contemporary Indian and Atlantic Oceans were land areas. In the western part of the Mediterranean Sea, west of the Apennines and north of Algeria and Tunisia, there were large erosional areas in the Mesozoic and the Paleogene which subsided in the late Tertiary and early Quaternary periods.

According to A.D. Arkhangelskiy and N.M. Strakhov [1], there were submarine elevations and shallow zones in certain parts of the Black Sea.

Under all the above seas, including the Black Sea, the thickness of the earth's crust is close to that under oceans, according to geophysical data. Some explorers are inclined to explain this fact by the presence of recent lands in these and directly adjacent areas or by relicts of original oceans. However, in the first case a very thick sial layer consisting of porous sediments should be found in these areas. Thus, the study of the geologic past discloses the existence in areas adjacent to the Mediterranean basin of eroded elevations and active volcanoes since the Paleozoic, near which large mountains and plateaus developed since the Mesozoic. Therefore, the above seas had sufficient amounts of sedimentary material, at least during the last 200 million years, since the end of the Paleozoic, and could accumulate terrestrial, volcanic, organic, and chemical sediments. Taking the sedimentation rate as 0.1 millimeter per year, considerably less than the contemporary seas actually accumulate, a 20 kilometer-thick layer should have been formed during those 200 million years. It is obvious that compensation of the sediments requires gradual subsidence of these parts of the earth's crust, and the 20-kilometer thick sedimentary layer should be reflected in the geophysical survey. But this is not the case.

The Red Sea separating the Arabian Peninsula from the African shore is even more informative. It is indisputable that the sea occupying a graben formed at the expense of an old shield, probably in late Mesozoic, should have underneath a sial layer of the same thickness as the adjacent shield. However, we have here a sial layer sharply decreased in thickness, and the gravimetric measurements are close to those known in normal oceans. Consequently, if the most recent geophysical data is correct, explanation must be found for the disappearance of the sial layer that undoubtedly existed under the Red, Mediterranean, Black, Bering, Japanese, and some other seas.

V.V. Belousov [4] expressed the opinion that the sial layer in these cases might have been dissolved in underlying ultrabasic magma. However, this explanation meets with the objection of geophysicists who state that the earth's crust and the underlying ultrabasic layer are solid and do not contain centers of molten magma of any significant size. It is obvious that the simple solution of subsiding sial is impossible according to the principle of physical chemistry.

R.W. Bemmelen [30] assumes that the basification of the sial layer in certain areas as a result of intrusion of great amounts of basic and ultrabasic magma, which explains the formation of large intrusive bodies accompanied by synchronous "transformation" of surrounding acidic rocks. Consequently, according to R.W. Bemmelen, the parts of the earth's crust which begin to sag as a result of increased weight, "oceanize" (a term suggested by the author). However, this assumption cannot explain the presence of geoidal boundaries established by geophysical survey between various spheres of the sial layer. Should transformations in the internal composition of the earth's crust have taken place merely as a result of intrusions, the boundaries -- especially the top of the basification -- would not be geoidal.

The difficulties facing explorers in their attempts to interpret phenomena accompanying oceanization may to a certain degree be defined if it is assumed that in the subsiding zones of the earth's crust metasomatism takes place in a direction opposite to that shown by D.S. Korzhinskiy for zones of elevation where granitization develops.

The hypothesis that the lower part of a

subsiding sial block melts (dissolves in peridotitic magma) or is plastically squeezed, must be rejected because of the relatively low temperatures and pressures in the zone of basification and because of the solid state of the zone. Because the sial layer in oceans is about 10 kilometers thick and about half of this thickness corresponds to the lower "basaltic" layer, the active metasomatic processes probably begin at about this depth, where, according to approximations, the temperature must be approximately 500 to 800 degrees centigrade and the pressure approximately 4,000 to 6,000 atmospheres. There is good reason to believe that the lower part of the sial is affected by iron-magnesium solutions penetrating from the peridotitic layer. Basification of granitoid rocks may take place not instantly, but in a certain sequence: first the metasomatic mafic minerals increases in quantity until the rock turns into a melanocratic migmatite. The next stage of metasomatism causes biotitization and amphibolization and in the final stage, a rock of basic composition is produced.

D.S. Korzhinskiy, in a personal communication, had the kindness to draw attention to the fact that inter-magmatic magnesium solutions, undersaturated in silica, originating in lower layers must react with the quartz of subsiding rocks, and replace it with orthorhombic pyroxene, while the alkaline feldspars must be, in the early stages of metasomatism, replaced by biotite, nepheline, and basic plagioclase. Depending on the composition of the rocks within the subsiding sial crust (granite, feldspathic, or quartz sandstone, clay and limestone), metasomatic replacement produces various rock types of intermediate or basic composition. The products of the initial stage of metasomatic basification generally form a layer whose composition is similar to that of gabbro, and therefore the layer is called basalt by geophysicists. The presence of such a layer, bound to the overlying granitic-sedimentary mantle by a gradual transition, can be detected everywhere in the earth's crust.

The "basaltic" sphere, having a relatively low temperature and pressure which decreases upward, consists of rocks of a variety of mineral compositions, always remaining, however, within the group of basic rocks. At depths of over 10 kilometers the physico-chemical conditions are more constant and, consequently, metasomatism must here proceed as in a stable environment, where, according to D.S. Korzhinskiy, the replacement does not take place gradually but instantly involves one sphere after another, and its sharply pronounced front moves upward. Therefore, the boundary between the "basaltic" layer and its basement, readily turned into a peridotitic rock as a result of the final stage of metasomatism, must be sharp. This can really be observed, for the Mohorovicic surface sharply separates the sialic crust from its ultrabasic substratum.

We may assume that in the course of subsidence, the lower portions of the sial shield turn into peridotitic rocks one after another and join the underlying substratum, and the Mohorovicic discontinuity moves into stratigraphically higher positions, remaining, however, at about the same depth all the time. The rocks of a subsiding part of the earth's crust drop below the Mohorovicic discontinuity, and a part of the sial of the involved area of the planet turns into sima and joins the peridotitic substratum.

In the light of known physical and chemical laws, basification, as D.S. Korzhinskiy states, is a phenomenon much simpler and more natural than granitization of rocks resting upon an ultrabasic layer.

A number of historic geologic conclusions and geotectonic considerations lead us to the idea that the earth shrinks because of the increased density of its constituent materials, as a result of the cooling off that in turn partially results from the loss of radioactive heat, and some large blocks of the earth's crust subside. The transformation of sial as a result of subsidence must finally lead to a nearly complete disappearance of this layer as well as all granites. This is the reason that in other planets which have passed the present stage of development of the earth, there can be neither a sialic crust nor granitoid rocks. The planet whose fragments fall onto the earth in the form of meteorites obviously broke into pieces after it passed into its final stage of evolution, when a uniform, nearly ultrabasic composition of the planet was established.

* * *

The number of problems related to the origin of granite is extremely large. Without considering this in its full extent, let us summarize the conclusions which may be drawn on the basis of the above facts and reasoning.

Granite is one of the typical elements constituting our planet and is formed at a certain stage of its development as a result of specific physical and chemical conditions inherent in the earth's external sphere.

In the Precambrian, the weathering of the original sima crust of the earth was very

intensive and substantial tectonic activity led to the formation of a great number of elevations and depressions, which contributed to the accumulation of the altered and graded material into thick sedimentary mantle. A sial crust emerged everywhere but covered the planet non-uniformly.

The chemical and physical weathering of the original sima sphere that took place during the early stages of the earth's history (in early Archaean time) led to the extraction of large amounts of iron and magnesium compounds and to their precipitation from solutions. Because of this, Precambrian rocks became rich in iron ore deposits.

V.A. Obruchev [20] draws attention to this fact in stating that the conditions during Archaean and Algonkian time were favorable for deposition of iron ore. N.M. Strakhov [25] demonstrated convincingly that the overwhelming majority of iron ore deposits were formed during the oldest Precambrian epoch of the earth's development, and during later periods the amount of sedimentary iron in the deposits was sharply reduced. This is understandable, for the surface of the planet became enveloped by a sial crust and the new supply of sima rocks rich in iron sharply decreased. Magnesium compounds were similarly reduced in quantity in Precambrian rocks.

During the Precambrian, a substantial amount of the dissolved magnesium resulting from the decomposition of basic rocks became concentrated in sea water and eventually formed thick layers of dolomite. Later, the supply of magnesium decreased and precipitation of dolomite slowed down (during the Paleozoic) and even ceased entirely in the Mesozoic and Cenozoic eras.

During the accumulation of the sial crust, especially in elevated zones, metasomatic processes took place because of specific physical and chemical conditions prevailing in these areas, and a complex of metamorphic formations, and their partial granitization, resulted.

The concept presented in this article considers sedimentary differentiation and chemical weathering to be essential to the formation of the sial layer, but does not exclude the possibility of a new supply moving up from below, increasing the thickness of the earth's crust. This possibility is indicated by the so-called "mountain roots," the thick sial layer beneath high elevations. It is clear that the lower part of these sial thickenings result from metasomatic exchange between the peridotitic layer and the roots of surface elevations. However, under basins, metasomatism is of the opposite nature; here the sial layer turns into rocks, first of basic (basaltic layer), then ultrabasic composition and joins the peridotitic layer.

The relatively small amount (about 1 percent by volume) of granite in the total composition of the earth and the disappearance of the sial layer as depth increases indicate that granites can by no means be considered the result of magmatic differentiation, for in this case the share of the sial layer in the total composition of the earth would have been greater. The contrary is most likely -- the sial layer, formed at a certain stage of the earth's development, is presently supplemented by new acidic rocks at a rate slower than its destruction. The reason is that the increased density of the planet leads to subsidence of large blocks of the earth's crust. Thus, in the early stages of the geologic development of the earth, its entire surface experienced intensive tectonic movements. Later, beginning in the Proterozoic, quite different circumstances began to stabilize the crust. At that time, new large shields emerged and more or less stable continents and oceans began to develop. Further, in the course of the formation of new, tectonically less active areas and the continued consolidation of our planet, conditions frequently developed which caused large areas of the sial layer to subside.

The above concept is fully consistent with the views of a number of scientists, particularly those of V.V. Belousov [4], according to whom contemporary oceans are relatively young.[1]

Developing this concept still further, we may, with certain reservations, outline the course of later development of the outer sphere of the earth. Assuming continued compression of the earth, it is logical to assume that subsidence of large continental blocks will not cease. Consequently, the area of continents will decrease and the sial layer will turn into sima. Finally, a uniform average composition of the planet will be established. This average must correspond to the mineral composition most stable under given physical and chemical conditions and most likely will be close to ultrabasic. Thus, the sial layer, and particularly granites, belong specifically to a certain tentative stage of the earth's development; they emerged and will disappear in the course of

[1] Interesting ideas on transformation of the earth's crust in zones of subsidence were expressed by M. V. Muratov in his recent publication entitled The Origin of Ocean Basins (Biul. Mosk. O-va Ispyt. Prirody, Otd. Geol., No. 5, 1957).

its evolution. The sial layer and granitoid rocks characteristic of our planet must be very rare in the cosmos. This explains the fact that thus far no meteorites of acidic composition have been found.

How should one explain the magmatic activity that formed intrusive and extrusive rocks in the earth's crust? Apparently both the sima layer and its femic substratum are solid, hot, and under high pressure. In some cases, however, localized centers of molten magma may emerge at various depths. Such centers may be caused by a temporary disturbance of equilibrium as a result of locally-increased radioactive decay or a drop in pressure caused by discharge of a tectonic stress at great depth.

The newly formed magmatic center may be ultrabasic if it develops in the peridotitic substratum, or basaltic if it is located in the basalt layer, or finally, granitic if it is confined to higher levels within the sial sphere.

Basic extrusives gradually pass into acidic extrusives in the course of vulcanism.

This evolution indicates the cooling of the basic molten center at depth and melting of the sial layer because of decreased pressure at higher levels.

Since a granitic eutectic mixture is more easily meltable, abundance of acidic extrusives and the occurrence of granitoid intrusives at upper levels of fold zones are easy to explain.

Thus, while ultrabasic rocks are a product of the original magma developed in the peridotitic layer, basic and especially acidic intrusives are produced by palingenetic magma, formed as a result of melting of metamorphic and sedimentary rocks of the earth's crust.

Some of the above thoughts and conclusions perhaps cannot be justified on the basis of geophysics, petrology, or geochemistry. Besides, the accumulation of new facts or different interpretations of known ones may require alteration of some of the above views. Nevertheless, whatever happens, the readily-known characteristics of the structure and composition of the upper spheres of the earth require new hypotheses capable of synthesizing the available facts satisfactorily.

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NEW DATA ON MITRIDATITE

by

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INTRODUCTION

The term "mitridatite" was suggested by P.A. Dvoychenko in 1914 for a light green, earthy substance found in 1911 by S.P. Popov in iron ore deposits of Kamysh-Burun, Kerch Peninsula. The analytical data on this substance is presented in Table 1 (Assay 1).

The empirical formulas of the assayed phosphates are as follows (less $CaCO_3$ and $CaSO_4 \cdot H_2O$):

1) Light green earthy substance from Kamysh-Burun (mitridatite of P.A. Dvoychenko): $Ca_{0.63}Fe_{2.18}(PO_4)_2(OH)_{1.80} \cdot 2.21H_2O$;

Table 1

Components	S.P. Popov	F.V. Chukrov			A.V. Sidorenko	
	Kamysh-Burun	Novyy-Karantin	Kamysh-Burun		Kamysh-Burun	Zheleznyy Rog
MgO	Traces	0,71	0,96	1,04	Traces	0,03
CaO	12,43	12,26	16,06	12,28	11,52	8,37
MnO	2,10	0,79	0,45	0,47	0,25	0,51
FeO	0,29	0,78	0,52	1,86	0,90	4,56
Fe_2O_3	37,81	31,54	36,69	31,57	40,06	21,63
CO_2	5,28	—	0,65	2,06	1,29	3,32
P_2O_5	30,09	24,48	30,61	22,16	27,67	13,35
SO_3	—	2,66	0,08	0,47	Traces	—
H_2O^+			8,82	7,19		
H_2O^-	11,83	18,99	4,26	7,57	13,82	11,85
Insoluble residue	—	8,19	0,32	12,61	4,92	35,43
Total . . .	99,83	100,40	99,42	99,28	100,43	99,05

Note: Comma represents decimal point.

Later, minerals which were outwardly and chemically similar to that called mitridatite by P.A. Dvoychenko were described by F.V. Chukhrov [3, 4] and A.V. Sidorenko [1, 2]. Chukhrov studied greenish products of weathered anapaite found in the Novyy-Karantin mine and weathered substances of the Kamysh-Burun deposit which bore a close, outward resemblance to mitridatite and were partially formed as an alteration product of oxykertschenite (Table 1, assays 2, 3, and 4).

A.V. Sidorenko [1, 2] published the chemical analyses of the greenish products of weathered anapaite from Kamysh-Burun, Kerch Peninsula and from Zhelez-naya Balka, Taman Peninsula (Table 1, assays 5 and 6).

2) The weathered product of anapaite from the Novyy-Karantin mine: $Ca_{1.24}Fe_{2.34}(PO_4)_2(OH)_{3.50} \cdot 4.00H_2O$;

3) The mineral from Kamysh-Burun in scirrhus form: $Ca_{1.40}Fe_{2.16}(PO_4)_2(OH)_{3.28} \cdot 1.73H_2O$.

4) The mineral from Kamysh-Burun forming veinlets: $Ca_{1.40}Fe_{2.58}(PO_4)_2(OH)_{4.52} \cdot 2.92H_2O$.

5) The weathered product of anapaite from Kamysh-Burun: $Ca_{0.98}Fe_{2.56}(PO_4)_2(OH)_{3.64} \cdot 2.11H_2O$.

6) The weathered product of anapaite from

Zheleznaya Balka: $Ca_{1.54}Fe_{2.88}(PO_4)_2(OH)_{5.72} \cdot 4.14\ H_2O$.

For mitridatite, F.V. Chukhrov suggested an approximate formula: $3CaO \cdot 2Fe_2O_3 \cdot 2P_2O_5 \cdot 3H_2O \cdot n$ aq. A.V. Sildorenko suggested a general formula (Ca, Mg, Mn, Fe)O$\cdot F_2O_3 \cdot P_2O_5 \cdot 3\text{-}6\ H_2O$, for the entire group of minerals, united under the name mitridatite. Frondel [8] expressed an opinion that analytical data on mitridatite may indicate not one but various minerals. For mitridatite itself he suggested the following formula: $CaFe_2(PO_4)_2(OH)_2 \cdot n\ H_2O$ (?). Later, F.V. Chukhrov [6] showed that various mitridatites studied by him have identical or very close positions and intensity of lines in the X-ray powder diagrams, which indicates the existence of a mineral of definite crystalline structure.

In this article, the study of new mitridatite samples by means of various modern research methods will be discussed.

CHEMICAL COMPOSITION

The samples analyzed for this study were collected by F.V. Chukhrov and V.I. Stepanov. Samples 1 and 2 are from the Yanysh-Takil deposit, and samples 3, 4, and 5 from the Novyy Karantin deposit.

Sample 1. Earthy, tobacco-green aggregates -- crystallization is incomplete; individual particles are elongated; the largest of them are 0.001 to 0.006 milimeters in length; the mineral is anisotropic, $n\beta$ = 1.765 ± 0.003.

Sample 2. Massive, dark tobacco-green aggregates -- finely crystalline; particles less than 0.001 millimeters in length; some grains are 0.03 millimeters long; mineral appears to be biaxial, optically negative, elongation positive, pleochroism is weak and ranges from yellowish-brown to yellowish-grey shades, $n\alpha$ = 1.770; $n\gamma$ = 0.762.

Sample 3. Almost massive, green encrustations of the matrix are less than 0.001 millimeters long; the greatest elongated particles are 0.006 by 0.03 millimeters in length; anisotropic, elongation positive, $n\beta$ = 1.77 ± 0.003.

Sample 4. Quite massive, tobacco-green aggregates -- porous on margins, earthy; substance is hardly crystallized; particles less than 0.001 millimeter in length prevail; mineral is anisotropic, $n\beta$ = 1.755.

Sample 5. Massive and powderlike aggregates -- tobacco green; the powderlike substance is crystalline; particles are 0.001 millimeter in length and smaller; mineral is anisotropic, $n\beta$ = 1.773 ± 0.003.

The chemical analyses of mitridatite, are compiled by V.A. Moleva in Table 2. The specific gravities were determined by V.S. Amelina.

The silica content in three samples of the mineral is as follows:

Sample 1: 0.48 percent SiO_2
Sample 2: 0.42 percent SiO_2
Sample 3: 0.42 percent SiO_2

The formula of the mineral is calculated on the assumption that a part of (PO_4) is replaced by $(OH)_4$, as for example, in fairfieldite [9]. The (OH) coefficients are derived from analytical data.

Ca bound to CO_2 and Al presumably bound to admixed silica are excluded from the calculated formulas.

The formulas of the analyzed mitridatites are:

Sample 1. $Ca_{0.61}Fe_{1.00}[(PO_4)_{0.87}(OH)_{1.42}] \cdot 0.86\ H_2O$; $\dfrac{\text{OH determined}}{\text{OH calculated}} = \dfrac{1.42}{1.60} = 0.89$

Sample 2. $Ca_{0.61}Fe_{1.00}[(PO_4)_{0.89}(OH)_{1.48}] \cdot 0.52\ H_2O$; $\dfrac{\text{OH determined}}{\text{OH calculated}} = \dfrac{1.62}{1.55} = 1.05$

Sample 3. $Ca_{0.59}Fe_{1.00}[(PO_4)_{0.94}(OH)_{1.48}] \cdot 0.62\ H_2O$; $\dfrac{\text{OH determined}}{\text{OH calculated}} = \dfrac{1.48}{1.36} = 1.09$

Sample 4. $Ca_{0.63}Fe_{1.00}[(PO_4)_{0.92}(OH)_{1.19}] \cdot 0.52\ H_2O$; $\dfrac{\text{OH determined}}{\text{OH calculated}} = \dfrac{1.19}{1.50} = 0.79$

Sample 5. $Ca_{0.69}Fe_{1.00}[(PO_4)_{0.96}(OH)_{1.59}] \cdot 0.56\ H_2O$; $\dfrac{\text{OH determined}}{\text{OH calculated}} = \dfrac{1.59}{1.50} = 1.06$

Ca—0.63; (PO_4)—0.92; H_2O—0.6; the average ratio $\dfrac{\text{OH determined}}{\text{OH calculated}} = 0.97$ indicates the determined and calculated (OH) values are adequately close. The formula of the mineral according to five analyses is:

$$Ca_{0.63}Fe_{1.00}(PO_4)_{0.92}(OH)_{1.50} \cdot n\ H_2O.$$

The recalculation of the analytical data from three samples of the same type mineral described by F.V. Chukhrov (1937) gives the following formulas:

Novyy-Karantin (Assay 2, Table 1):

$Ca_{0.57}Fe_{1.00}[(PO_4)_{0.87}(OH)_{1.53}] \cdot 1.75\ H_2O$ [(OH) coefficient as calculated].

Table 2

Component	Yanysh-Takil Deposit						Novyy Karantin Deposit								
	Sample 1			Sample 2			Sample 3			Sample 4			Sample 5		
	%	Molecular amounts	Number of atom cations	%	Molecular amounts	No. of atom cations	%	Molecular amounts	No. of atom cations	%	Molecular amounts	No. of atom cations	%	Molecular amounts	Number of atom cations
MgO	0,72	0,018		0,60	0,015		0,27	0,007		0,38	0,009		0,55	0,014	
CaO	15,74	0,281	0,290	16,54	0,295	0,296	16,10	0,287	0,285	17,04	0,304	0,306	17,56	0,313	0,319
SrO	0,26	0,003		0,27	0,003		0,30	0,003		0,24	0,002		0,28	0,003	
MnO	0,30	0,004		0,30	0,004		0,36	0,005		0,50	0,007		0,44	0,006	
Fe_2O_3	37,84	0,237	0,474	38,60	0,242		38,48	0,241		38,80	0,243	0,486	37,04	0,232	0,464
Al_2O_3	0,36	0,003		0,32	0,003	0,484	0,92	0,009	0,482	0,40	0,004		0,56	0,005	
CO_2	0,72	0,016		0,92	0,021		0,77	0,017		0,70	0,016		0,77	0,017	
P_2O_5	29,20	0,206	0,412	30,84	0,217	0,434	31,08	0,226	0,452	31,90	0,225	0,450	31,59	0,222	0,444
H_2O^+	6,08	0,338	0,676	7,08	0,398	0,786	6,43	0,357	0,714	5,20	0,289	0,578	6,66	0,370	0,740
H_2O^-	7,36	0,409	0,818	4,52	0 251	0,502	5,36	0,298	0,596	4,56	0,253	0,506	4,64	0,258	0,516
Insoluble residue	1,36	—		0,16	—		0,16	—		0,40	—		0,20	—	
Total	99,94			100,15	—		100,23	—		100,12	—		100,29	—	
Sp. gr.	2,961			2,950			3,064			3,039			3,059		

The volumetric weight of mitridatite (Sample 2) is 2.594; this indicates the presence of fine pores in the mineral aggregates.

Note: Comma represents decimal point.

Kamysh-Burun deposit, scirrhus (Assay 3, able 1):

$a_{0.67}Fe_{1.00}[(PO_4)_{0.94}(OH)_{2.13}] \cdot 0.51\ H_2O;$

$$\frac{\text{H) determined}}{\text{H) calculated}} = \frac{2.13}{1.52} = 1.40.$$

Kamysh-Burun, veinlets (Assay 4, Table 1):

$a_{0.57}Fe_{1.00}[(PO_4)_{0.79}(OH)_{2.02}] \cdot 1.03\ H_2O;$

$$\frac{\text{H) determined}}{\text{H) calculated}} = \frac{2.02}{1.77} = 1.14.$$

The average coefficients of the mitridatite ormula, calculated according to the data of ight assays are:

a—0.62; (PO_4)—0.90; H_2O—0.79; the aver-ge ratio $\frac{\text{(OH) determined}}{\text{(OH) calculated}} = 1.06$

The mitridatite formula, according to the verage coefficients calculated on the basis f eight assays is:

$a_{0.62}Fe_{1.00}(PO_4)_{0.90}(OH)_{1.54} \cdot n\ H_2O.$

The tripled coefficients of the formula ive:

$a_{1.86}Fe_{3.00}(PO_4)_{2.70}(OH)_{4.61} \cdot n\ H_2O$

where average n approximates 2. Taking the coefficient for Ca as 2, we get the following mitridatite formula:

$$Ca_2Fe_3[(PO_4)_3(OH)_4] \cdot nH_2O.$$

The theoretical composition of the mineral of this formula, if n = 2, is:

CaO	17.61
Fe_2O_3	37.62
P_2O_5	33.46
H_2O^+	5.655
H_2O^-	5.655
Total	100.00

The fluctuations in the content of the principal components in mitridatite may be explained by replacement of a part of (PO_4) by $(OH)_4$. Assuming such a replacement, we get the following formula for the mineral:

$$Ca_2Fe_3(PO_4)_{3-x}(OH)_{4+3x} \cdot nH_2O$$

Taking the coefficients (PO_4) calculated from the analyses, we get the following mitridatite formulas (1 to 5, new analyses; 6 to 8, analyses published in 1937 by F.V. Chukhrov). Along with the theoretical coefficients, we give (in parentheses) the coefficients calculated according to analytical data:

1) $Ca_{2,00(1.83)}\ Fe_{3,00}\ (PO_4)_{2,61}\ (OH)_{5,17}\ (4,26) \cdot nH_2O$

2) $Ca_{2,00(1,83)}\ Fe_{3,00}\ (PO_4)_{2,67}\ (OH)_{4,99}\ (4,86) \cdot nH_2O$

3) $Ca_{2,00(1,77)}\ Fe_{3,00}\ (PO_4)_{2,82}\ (OH)_{4,54}\ (4,44) \cdot nH_2O$

4) $Ca_{2,00(1,89}\ Fe_{3,00}\ (PO_4)_{2,76}\ (OH)_{4,72}\ (3,57) \cdot nH_2O$

5) $Ca_{2,00(2,07)}\ Fe_{3,00}\ (PO_4)_{2,88}\ (OH)_{4,36}\ (4,77) n \cdot H_2O$

6) $Ca_{2,00(1,71)}\ Fe_{3,00}\ (PO_4)_{2,61}\ (OH)_{5,17}\ nHO_2$

7) $Ca_{2,00(2,01)}\ Fe_{3,00}\ (PO_4)_{2,82}\ (OH)_{4,54}\ (6,39) \cdot nH_2O$

8) $Ca_{2,00(1,71)}\ Fe_{3,00}\ (PO_4)_{2,37}\ (OH)_{5,89}\ (6,06) . nH_2O$

The average formula according to the eight analyses is:

$$Ca_{2,00(1,85)}\ Fe_{3,00}\ (Po_4)_{2,69}(OH)_{4,93}\ (4,90)._{nH_2O}$$

According to Frondel [8], defects of the crystal lattice is one of the possible reasons for deviation in the coefficients in the formulas of iron phosphates such as dufrenite and rockbridgeite; this assumption cannot be proved for mitridatite, because its crystal structure is still unknown.

The formulas for calcium iron phosphates whose composition is close to that of mitridatite are shown below.

fourcherite	$Ca_2Fe^{3+}_8(PO_4)_4(OH)_{16}\cdot 14H_2O$; Ca : Fe = 0,25.
vorickyite	$Ca_2Fe^{3+}_{10}(Po_4)_4(OH)_{22}\cdot 6_2HO$; Ca : Fe = 0,20.
richellite	$Ca_3Fe^{3+}_{10}(Po_4)_8(OH,F)_{12}\cdot nH_2O$; Ca : Fe = 0,30.
phosphate gel from Baraun (Czechoslovakia)	$Ca_{2,16}Fe^{3+}_{7,44}(PO_4)_4(OH)_{4,64}\cdot nH_2O$; Ca : Fe = 0,29.
gel-like phosphate from the Taman Peninsula	$Ca_{12,12}Fe^{3+}_{5,20}(PO_4)(OH)_{7,84}\cdot nH_2O$; Ca : Fe = 0,41.

The above formulas show that the gel-like phosphate from Zheleznaya Balka, Taman Peninsula, is the closest one to mitridatite among the five minerals. No complete analog of mitridatite is known from minerals described in the literature.

Laubmanite $Fe_3^{2+}Fe_6^{3+}(PO_4)_4(OH)_{12}$ and andrewsite $(Cu, Fe^{2+})_3Fe_6^{3+}(PO_4)_4(OH)_{12}$ are the closest phosphate minerals to mitridatite in terms of principal components.

ELECTRON MICROSCOPIC STUDY

For electron microscopic study, we selected earthy, powder-like samples of mitridatite giving fine suspensions in water.

The particles of which the aggregates of mitridatite are composed were analyzed by the ultrasonic method. Figure 1 shows mitridatite particles and their aggregates after being turned into dust. This and other photographs show that the finest mitridatite particles are platy in form and some of them have crystal outlines.

X-RAY AND ELECTRONOGRAPHIC STUDY

Interplanar distances of the lattice of the analyzed mitridatite samples, calculated by M. T. Yanchenko, are compiled in Table 3. This table also presents interplanar distances of mitridatite from the Kamysh-Burun deposit

Fig. 1. Electron-microscope photograph of mitridatite; magnified 30,000X.

Table 3

Yanysh-Takil Deposit				Novyy-Karantin Deposit					
Sample 1		Sample 2		Sample 3		Sample 4		Sample 5	
d	J	d	J	d	J	d	J	d	J
8,74	7 (width)	8,81	7 (width)	8,60	6 (width)	—	—	8,35	5 (width)
5,57	6	5.57	8	5,60	8	5,49	4	5,60	6
		3,49	2	3,48	1	—	—	3,20	6
3,19	7	3,19	6	3,18	5	3,20	6	3,02	3
		3,02	3	3,02	2	—	—	2,73	10
3,02	2	2,90	3	2,88	2	—	—		
2,73	10	2,73	10	2,73	10	2,73	10		
2,56	7	2,56	6	2,57	6	2,57	4	2,57	6
2,43	1	2,46	1	2,46	2				
2,19	5	2,18	4	2,17	5	2,19	2	2,18	4
2,10	2	2,10	3	2,10	3			2,10	3
1,919	2	1,911	3	1,919	4			1,931	1
				1,820	1				
				1,780	2			1,785	2
1,731	2	1,750	2	1,745	2			1,745	1
1,614	7	1,616	7	1,614	7	1,612	5	1,612	8
1,553	3	1,553	3	1,555	3			1,553	2
				1,483	2				
1,419	1	1,415	2	1,415	1				
				1,396	1				
				1,372	1				

ote: Comma represents decimal point.

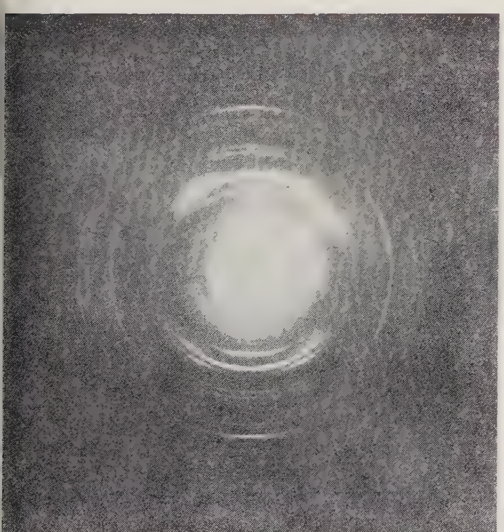

Fig. 2. Electronogram of the mitridatite texture

Table 3 shows that the analyzed mitri- itites are nearly identical in their crystal iase.

A.A. Voronova calculated interplanar dis- inces of mitridatite (samples 2 and 5) on the isis of electronographic studies (Table 4).

A comparison of Tables 3 and 4 reveals that the interplanar distances of mitridatite calculated by the X-ray method and measured from electronograms nearly coincide. The slides of mitridatite suspensions on celluloid films show a texture consisting of uniformly oriented particles. Electronograms of these textures were obtained by turning the slide at an oblique angle to the beam of electrons (Figure 2). On the basis of these electronograms, mitridatite appears to crystallize in the monoclinic or triclinic systems. A complete calculation and an interpretation of the electronograms could not be carried out because of an inadequate number of reflections and their great length.

THERMAL STUDY

Mitridatite changes on heating as follows:

1. Up to 350°C the color of the mineral hardly changes, but after being at this temperature for six hours the mineral becomes brownish.

2. At 550° C the mineral becomes yellowish brown (with a greenish shade); after being at this temperature for six hours, the color

Table 4

Sample 2		Sample 5		Sample 2		Sample 5	
d	J	d	J	d	J	d	J
5,56	10	5,54	10	1,830	5	1,824	6
3,22	10	3,20	10	1,745	8	1,73	8
2,74	9	2,741	10	1,620	10	1,61	10
2,58	4	2,8	6	1,600	2	1,542	2
2,21	9	2,21	9	1,479	8	1,471	5
2,11	8	2,10	9	1,400	5	1,382	2
1,936	1			1,347	3		
1,860	5	1,85	6	1,054	3		

Note: Comma represents decimal point.

becomes cherry-red to iron-black and remains the same with further annealing up to 750° C.

The interplanar distances for two mitridatite samples, annealed at 350°, 550°, and 750° C, are compiled in Table 5.

A comparison of Tables 3 and 5 shows that the crystalline phase of mitridatite is demolished after six hours of annealing at 350° C. Then the X-ray powder photographs show blurred lines of the residual crystalline phase of mitridatite. At 500° there appears a new (dehydrated) crystalline phase, which remains stable up to 750° C.

The curves of dehydration on annealing were made in the laboratory under A.I. Tsvetkov for several mitridatite samples from various parts of the Kerch Peninsula; the curves of different samples are very similar or even completely identical. Typical curves are shown in Figure 3.

In reviewing the dehydration curves, the conclusion may be drawn that mitridatite begins to lose its water at a temperature of about 100° C; at the interval from 100° to 400° C, the mineral loses the principal part of its water content, and at the interval between 400° and 500° C nearly all of the remainder.

The curves of heating show the maximum break at 280° C, when the relatively weakly-bound water is extracted. The loss of this water ends at 350° C. This is consistent with the curve of dehydration. It is remarkable that the annealing curves show the sharpest break, corresponding to the loss of relatively weakly bound water, in Sample 1, in which the water content was the highest.

All the annealing curves show breaks at 405 to 425° C and an exothermal effect with a maximum between 675 and 705°; the annealing curve of Sample 1 shows another weak exothermal effect, with a maximum at about 600° C. This effect is absent in the annealing curves of the other samples.

The stop having its maximum between 405 and 425° C apparently corresponds to the loss of hydroxyl water, for this break ands at 500° C when the substance becomes dehydrated. The X-ray data disclose that the typical mitridatite lattice disappears at a temperature just below 550° C. The position of the exothermal effect having its maximum between 675 and 705° C does not essentially differ from those known for the annealing curves of other iron phosphates such as bosphorite and various kertschenites [6].

CONCLUSION

Mitridatite is a calcium-iron phosphate in which the $(OH)_4$ group seems to replace one or another part of the (PO_4). The chemical formula of the mineral is:

$$Ca_2Fe_3 \cdot [(PO_4)_3(OH)_4] \cdot nH_2O,$$

where n is 2 on the average. The crystal system is monoclinic or triclinic. The aggregates are cryptocrystalline, earthy, porous, or massive. The color is tobacco-green to dark green. It dissolves in acids. The index of refraction is $\beta = 1.77$. Some of the particles are of colloidal size; such particles look like thin plates under an electron microscope.

Mitridatite is an alteration product of oxykerchenite (calcium-rich) or of anapaite (with loss of calcium); mitridatite can possibly be formed also as a result of a direct precipitation from solution. Mitridatite may be considered a metacolloid containing varying amounts of colloidal particles.

Table 5

Sample 2 250°		Sample 1						Sample 5					
		350°		550°		750°		350°		550°		750°	
d	J	d	J	d	J	d	J	d	J	d	J	d	J
						3,65	4			4,47	1 (size)	3,86	1 (size)
						3,52	6			3,65	5	3,52	10
						3,31	8						
3,19	9	3,21	8 (size)			3,15	8	3,15	9 (size)	3,14	7	3,15	9
						2,84	9			2,83	6	2,84	7
2,71	10	2,69	10 (size)	2,67	10	2,69	10	2,71	10 (size)	2,70	10	2,69	8
				2,50	4 (size)	2,50	4			2,57	3	2,57	3
										2,48	2	2,51	5
2,25	7			2,25	2	2,25	4 (size)	2,17	5 (size)	2,39	3	2,37	4 (size)
2,14	6					1,905	2 (size)	2,04	5 (size)	2,29	2	2,19	2 (size)
										1,998	3	2,02	2
										1,910	2 (size)	1,905	3
										1,832	4 (size)	1,835	3
				1,845	4 (size)	1,820	3 (double)						
						1,805						1,692	6
						1,764	1			1,653	8	1,667	3
				1,692	6	1,692	5						
						1,667	2 (size)						
1,598	8	1,592	8 (size)			1,592	8	1,594	6 (size)	1,576	6	1,588	8
				1,542	3 (size)	1,542	5						
				1,483	6	1,483	5			1,540	2 (size)	1,483	6
				1,452	8	1,449	9			1,454	5 (size)	1,449	8
						1,375	3 (size)			1,413	5 (size)	1,400	2 (size)
				1,309	3 (size)	1,255	3 (size)					1,376	3 (size)
				1,256	3 (size)	1,197	4					1,198	4 (size)
						1,183	3 (size)					1,162	2 (size)
				1,142	3 (size)	1,139	2 (size)					1,139	2 (size)
				1,102	3 (size)							1,102	2
				1,055	3 (size)								

Note: Comma represents decimal point.

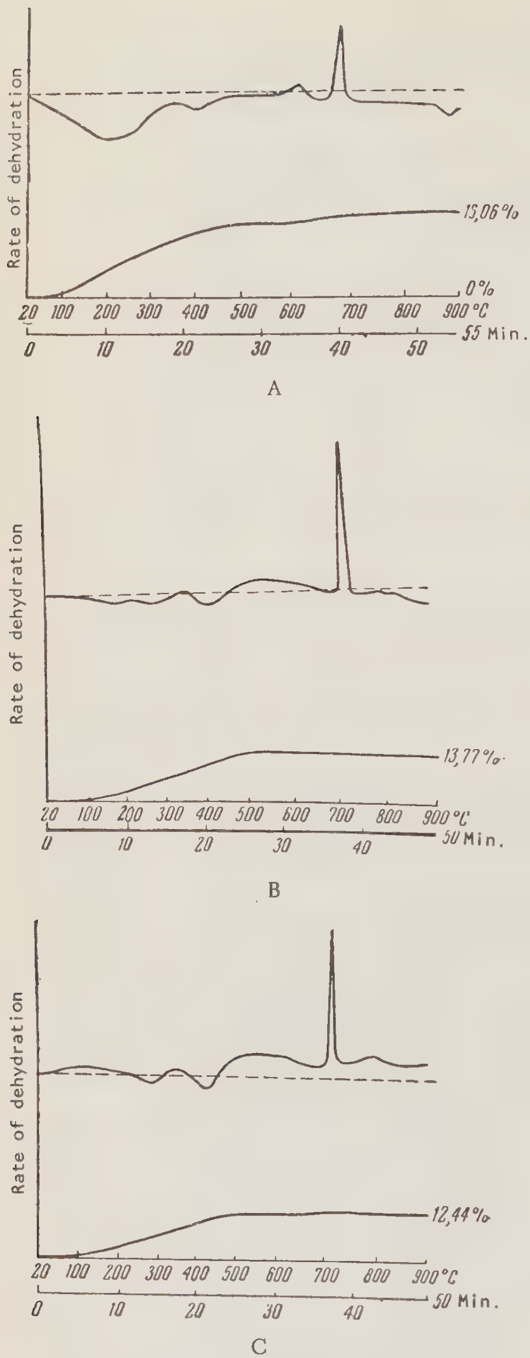

Fig. 3. Heating curves of mitridatite.

A -- sample 1; B -- sample 4; C -- sample 5.

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ALTERATION OF LUDWIGITE IN THE MAGNETITE DEPOSIT OF ZHELEZNYY KRYAZH IN THE EASTERN TRANSBAIKAL REGION

by

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In the contact-metasomatic iron ore deposit of Zheleznyy Kryazh, ludwigite was found in association with magnesian skarn, where it occurs as a relatively late metasomatic mineral.

Ludwigite develops most favorably in zones of forsterite skarn, usually serpentinized and containing some diopside, phlogopite, clinohumite, chondrodite, spinel, and other magnesium minerals. In such skarns, magnetite also develops metasomatically, even forming magnetite deposits. In the presence of ludwigite, magnetite usually fills in spaces between the prismatic crystals of ludwigite or occurs in the central parts of its bunch-like aggregates (Figure 1). In places, magnetite aggregates replace ludwigite, preserving its general outlines. Such a relationship implies a nearly synchronous precipitation of ludwigite and magnetite, the magnetite continuing to be precipitated when the ludwigite ceases. In some places, iron sulfides, predominantly pyrrhotite, also develop later, during the hydrothermal stage.

Thus the ludwigite-bearing rocks are mineral associations in which the relative content of waterless skarn minerals, such as ludwigite, magnetite, sulfides, and various secondary minerals is widely variable.

Ludwigite forms coarse, radial, and bunch-like aggregates, in which some prisms are 10 to 15 centimeters long, or granular aggregates of fine prismatic, differently-oriented crystals; in places disordered fibrous felt-like aggregates occur.

Fresh ludwigite is black with a silky, adamantine luster. As a result of decomposition and weathering, these properties gradually disappear. The mineral first loses its luster, then becomes lighter in some cases, but retains its dark color in others, and turns into a porous, amorphous mass.

As we mentioned, sulfide mineralization with pyrrhotite predominant is abundant in some parts of the deposit. Sulfides are distributed very irregularly in the skarn ore bodies, including those containing ludwigite; in some places sulfides occur in great amounts but are nearly absent in others.

Chemical assays of magnetite containing sulfides show up to 13 percent S at certain depths of drill holes in the area of Pad' Rudnichnaya. At some depths, pyrrhotite prevails over magnetite. Sulfide mineralization is accompanied by substantial alteration of borates. In the presence of small amounts of sulfides, unweathered and non-ascharitized ludwigite looks fresh, silky, or adamantine and only in places becomes dull because of partial ascharitization.

In the zones of higher sulfide content, for example, in the area of Pad' Rudnichnaya, the alteration of ludwigite can be seen in cores macroscopically.

The ludwigite-pyrrhotite samples recovered at different depths from drill holes reveal that altered ludwigite grains retain their form and structural relations but lose their luster and color or even turn into a porous, partially soot-like, amorphous mass. Concentrated HCl dropped upon such a mass produces H_2S, and this indicates the possible presence of fine, dispersed pyrrhotite or colloidal iron sulfides.

Under the microscope, one can see that fine-grained to crypto-crystalline aggregates of opaque ore minerals compose the greater part of the highly decomposed ludwigite rocks, in which small amounts of fine-grained, non-ore minerals may also occur. The interrelations and the disposition of ore and non-ore particles permit recognition of outlines of the decomposed ludwigite grains and even their former cleavage and fracture. In places, irregularly-shaped relict ludwigite grains can also be seen. In non-ore aggregates, locally occurring scales, fibers, and grains of chlorite, serpentine, brucite, hydromagnesite, and calcite can be recognized. They were determined by measuring refractive indices by the immersion method, with the Canada balsam of the slide washed off. In the majority of cases, fine dispersion of

Table 1

Chemical Assays of Selected Fresh Ludwigite from Zhelezny Kryazh (Central Chemical Laboratory of the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry)

Oxides	Assay 1, long radial ludwigite, Shirokiy Log, trench 155[1]	Assay 2, granular ludwigite, Pad' Rudnichnaya, drill hole[1]	Assay 3, disordered fibrous ludwigite, 8th section, (2nd gully)
SiO_2	0.08	0.66	0.80
TiO_2	--	--	traces
Al_2O_3	2.99	1.08	1.18
Fe_2O_3	36	28.85	24.46
FeO	13.62	21.33	10.70
MnO	not determined	not determined	0.27
MgO	23.25	24.80	38.81
CaO	1.14	1.34	0.00
H_2O^-	1.14	0.70	0.29
H_2O^+	8	7.63	6.99
B_2O_3	14.69	12.21	16.32
S	--	0.32	--
Total	100.84	99.92	99.64
Analyzed by	O.V. Uranova	O.P. Ostrogorskaya	

[1]Assays 1 and 2 from an unpublished article by I.A. Yefimov.

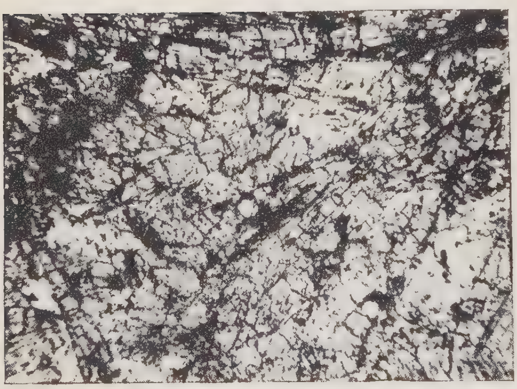

Fig. 1. Granular ludwigite

Dark gray--ludwigite; light gray--magnetite; black--hollows in the slide. Polished section, magnified 40X.

grains, their overlapping, and the richness in fine ore particles do not permit one to determine particular minerals, much less evaluate their distribution quantitatively.

Polished sections revealed some details of the ore minerals. In partially-altered ludwigite rocks, still containing macroscopically visible sulfides, there are pseudomorph aggregates after ludwigite, scattered grains of altered skarn minerals (forsterite and others), and pyrrhotite of the same size as the above components (Table 1).

The pseudomorph aggregates after ludwigite have typical prismatic and radial forms in which traces of the former ludwigite cleavages can be recognized; the aggregates consist largely of yellowish-grey and grey, fine-grained, barely reflecting masses in which fine dots and needles of pyrrhotite and non-ore minerals can be seen under a reflecting microscope. In thin sections, the majority of pseudomorphs are not transparent; most likely they consist predominantly of sulfides. It must be noted that no magnetite was found even at the highest magnification.

Pyrrhotite grains are fresh in places, but in other places they are partially replaced by extremely fine, hellowish-grey aggregates similar to those of pseudomorphs after ludwigite. The pyrrhotite grains or their aggregates are frequently cut by thin and irregular veinlets of magnetite which is younger than the granular magnetite of the ludwigite-magnetite ore. Similar veinlets of younger magnetite also occur commonly in pseudomorphs after ludwigite. However, it is still not clear whether they were formed after the replacement of ludwigite or before.

No sulfides can be seen under the microscope in samples of deeply-weathered ludwigite rocks having no macroscopically visible sulfides. Some pseudomorphs after ludwigite and scattered grains of altered

skarn mineral are similar to those described above but containing no visible pyrrhotite. Another difference is the presence of a number of thin, irregular, branched veinlets and irregularly-shaped spots of late magnetite occurring in places. The margins, and some of the central parts of such spots have bands of hematite aggregates and non-ore minerals which cannot be determined more specifically.

The electron microscope photographs of completely decomposed ludwigite taken in the Electron Microscopic Laboratory of the Institute of Geology of Ore Deposits, U. S. S. R. Academy of Sciences, magnified 13,000 times, distinguish separate mineral grains in the otherwise structureless mass of decomposition products of ludwigite (Figure 2). These grains, thousandths of a millimeter in size, have elongated, platy forms, and possibly are platy pyrrhotite.

Fig. 2. Electron-microscope photograph of decomposed ludwigite, magnified 13,000X.

The large grain (several microns in size) within the matrix of decomposed ludwigite is possibly a platy pyrrhotite with corroded margins.

Table 2 presents chemical assays of two ludwigite samples decomposed to different degrees. Magnetic minerals, primarily magnetite, were extracted by an electromagnet from finely ground samples prior to assaying.

The mineral compositions were computed from chemical assays in the following way:

1. The total B_2O_3 content was considered to be present in ludwigite; this required an equal molecular amount of Fe_2O_3 and a fourfold molecular amount of $MgO + FeO$. The molecular amounts of the two oxides were calculated according to the ratio $MgO:FeO = 6:3$, established by chemical assays of ludwigite from the Zheleznyy Kryazh deposit.

2. Of the molecular amounts of Fe_2O_3 and FeO, the amount of Fe occurring in the ludwigite was determined; subtracting this from the amount of Fe in the assay, we determined the Fe of sulfides and oxides combined; to this we added the amount of S. The actual content of each of these minerals could not be determined, hence the conclusions presented later in the text are only of a qualitative nature.

3. The molecular amount of SiO_2 present was considered to be bound to serpentine; the corresponding molecular amounts of MgO and H_2O were then added; because of the low serpentine content, iron included in it was disregarded.

4. The remaining MgO and an equal molecular amount of H_2O were believed to form brucite.

After these calculations, there was excessive Al_2O_3 and H_2O; the excessive Al_2O_3 in assay 38-15 amounted to 3.5 units and that in assay 38-13 to 4.0 units. A part of the alumina, especially in assay 38-15, is in one way or another bound to ludwigite relicts; another part is apparently present in chlorite.

Because of the small weight of the assayed samples, H_2O^+ and H_2O^- were not determined separately. A part of the excessive water is undoubtedly hygroscopic moisture and the rest is possibly derived from iron hydroxides.

The recalculations provided the relative proportion of the minerals in each of the two analyzed samples in molecular percentages, as shown in Table 3.

The following preliminary conclusions may be drawn concerning the unclassified group of sulfides and iron oxides: pyrrhotite and bisulfides such as pyrite, marcasite, and melnikovite may be present. Of the iron oxides, magnetite (remaining after magnetic separation), hematite, and iron hydroxide are possible. In assay 38-15, the molecular amount of sulfur is higher than the corresponding molecular amount of Fe normally present in this group of minerals. Thus, the presence here of iron bisulfides is inevitable, and their amounts must be greater the higher the iron oxide and pyrrhotite content. The presence of pyrrhotite is proved by the X-ray powder photographs. However, the photographs do not show bisulfide lines; therefore, bisulfides apparently occur in gel form.

In sample 38-13, the molecular amount of S is less than the molecular amount of Fe in the combined group of sulfides and iron oxides. It could be concluded therefore,

Table 2

Chemical Assays of Nonmagnetic Fractions of Decomposed Ludwigite Rocks and Their Calculated Mineral Compositions

Components	Weight Percent	Molecular Amount	Ludwigite Ore (Mg, Fe··) Fe··· BO_5 or 4(Mg, Fe) O · Fe_2O_3 · B_2O_3	Sulfides and Iron Oxides	Serpentine 3MgO · · $2SiO_2$ · · $2H_2O$	Brucite $Mg(OH)_2$	Excess
Sample 38-15							
SiO_2	3,98	66	—	—	66	—	—
Al_2O_3	0,34	3,5	—	—	—	—	3,6
Fe[1]	27,30	488	—	354,4	—	—	—
Fe_2O_3			53,8[2]	—	—	—	—
FeO			79,8[2]	—	—	—	—
MgO	29,56	733	205	—	99	429	—
CaO	traces						
B_2O_3	5,42	77	77	—	—	—	—
$H_2O\pm$	11,81	662	—	—	66	429	167
S	14,97	467	—	467	—	—	—
Total	—	2496,5	415,6	821,4	231	858	170,5
Molecular %	—	—	16,7	33	9,0	34,4	6,8
Sample 38-13							
SiO_2	4,46	74	—	—	74	—	—
Al_2O_3	0,41	4	—	—	—	—	4
Fe[1]	33,60	600	—	591,3	—	—	—
Fe_2O_3	—	—	3,5[2]	—	—	—	—
FeO	—	—	5,2[2]	—	—	—	—
MgO	23,74	588	13,3	—	111	463,7	—
CaO	traces	—	—	—	—	—	—
B_2O_3	0,40	5	5	—	—	—	—
$H_2O\mp$	11,96	664	—	—	74	463,7	126,3
S	17,73	554	—	554	—	—	—
Total	—	2489	27	1145,5	259	927,4	130,3
Molecular %	—	—	1,1	46,0	10,4	37,2	5,2

Assayed by A.I. Pokrovskaya and V.V. Kukharchik

Note: Comma represents decimal point.

[1]Total content

[2]Ferric and ferrous iron are recalculated as pure metals.

Table 3

Mineral Composition of Decomposed Ludwigites According to Recalculated Chemical Assays

Minerals	Sample 38-15	Sample 38-13
Ludwigite	16.7	1.1
Sulfides and iron oxides combined	33.0	46.0
Serpentine (including some chlorite)	9.1	10.5
Brucite (?)	34.4	37.2
Excess Al_2O_3 and H_2O	167.0	126.0
Total	100.0	100.0

that sulfides occur here in the form of pyrrhotite. This conclusion can be partly supported by electron microscope photographs. However, the X-ray powder photograph of the sample does not have pyrrhotite lines, nor does it have lines of other sulfides. Besides very small amounts of pyrrhotite in a finely dispersed state, sulfides occur here principally in gel form. Since iron oxides occur along with them and increase the relative sulfur content, gels of both monosulfide and bisulfide are possible.

As mentioned, the presence of brucite is tentatively suggested, for only a few grains of it were found in thin sections. Perhaps it occurs in particles of submicroscopic size, which cannot be seen in the presence of finely

dispersed iron oxides and sulfide aggregates. Consequently, it is possible that the substance considered to be brucite may actually be another mineral of closely related composition, such as ferrobrucite, hydromagnesite, etc.

Thus, the decomposition of ludwigite produces minerals containing no boron; boron becomes extracted in greater amounts the further the decomposition of ludwigite is advanced. The ludwigite decomposition is so extensive in the Zheleznyy Kryazh deposit that the boron content of the deposit is noncommercial.

We emphasize once again that such a decomposition of ludwigite can be detected in the core of drill holes only at depths where sulfide mineralization is very rich and can be seen macroscopically or established by hydrogen sulfide reduction with HCl.

Because the sulfide mineralization in the area of Pad' Rucnichnaya is extensive, most of the ludwigite in this area is decomposed to some degree. Still undecomposed ludwigite can be found in those parts of magnetite ore bodies where, for one or another reason, no sulfide solutions could circulate. According to chemical assays, such undecomposed ludwigite, associated with magnetite, contains 12 to 16 percent B_2O_3.

The partially decomposed ludwigite in one of the samples taken in an area rich in pyrrotite contained 7.88 percent B_2O_3 (drill hole 4, depth 6 meters, sample 4-31). In another, more decomposed sample we determined 5.42 percent B_2O_3 (drill hole 38, depth 50 meters). The most extensively decomposed ludwigite contains only 0.40 percent B_2O_3 (sample 38-13, depth 47 meters, Fig. 3), or even 0.014 percent B_2O_3 (sample 526, drill hole 5, depth 69 meters, Fig. 4). Thus, in the last two cases boron was almost completely extracted.

The last two samples were taken from the core of a drill hole at a depth of 50 to 80 meters. The question arises of whether or not these depths are within the zone of oxidation. However, no definite answer can be given. In the zone of oxidation, the decomposition of ludwigite could be explained by the action of acids resulting from sulfide oxidation. Drill cores in the area of Pad' Rudnichnaya, at a depth of 20 to 30 meters, recover sulfides consisting largely of more or less preserved pyrrhotite. The preservation of finely dispersed pyrrhotite in the pseudomorphs after ludwigite is especially significant. Such finely dispersed pyrrhotite should easily be oxidized in the oxidation zones.

Ludwigite rocks are altered still further at the surface, and in trenches as well as within the first few meters of drill holes. Here iron hydroxide develops because of the presence of iron sulfides, ludwigite, and other minerals; calcite replaces serpentine, chlorite, brucite, and hydromagnesite to varying degrees.

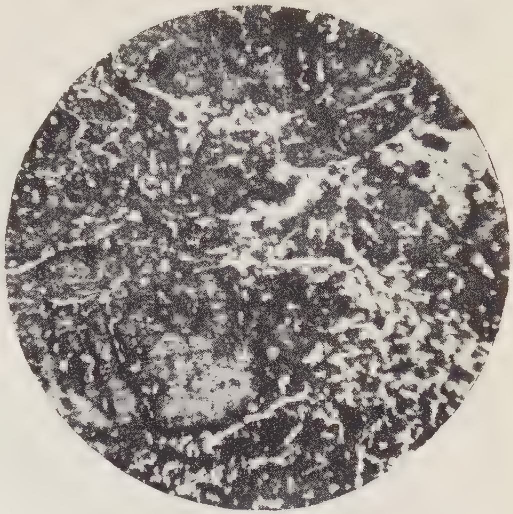

Fig. 3. Altered sulfidized ludwigite-magnetite rock.

Dark -- products of ludwigite decomposition; light -- magnetite. Sulfides are in a finely dispersed state and cannot be seen. Polished section. Sample 38-13, magnified 40X.

Fig. 4. Altered ludwigite-pyrrhotite rock.

Dark -- products of ludwigite decomposition; light -- pyrrhotite. Polished section, Sample 5-26, magnified 40X.

The sampling determined the presence of only small amounts, if any, of boron in the iron ore zones of some trenches in the Pad' Rudnichnaya area and in the upper part of Shirokiy Log, where the rocks consist of pseudomorphous mineral associations after ludwigite and relicts of ludwigite.

Thus, at the erosional surface and nearby, sulfidized products of ludwigite decomposition, from which boron has been extracted to some degree, became intensely oxidized and carbonized, and boron was completely extracted.

It must be noted that the replacement of decomposed ludwigite by calcite can also be seen in some thin sections of samples from deeper parts of the deposit. Here, calcite occurs in coarse-grained aggregates and seems to have been formed during a later hydrothermal stage. Under near surface conditions, the replacement of decomposed ludwigite rocks by calcite was extensive. In the preceding discussion we reviewed ludwigite rocks with primary sulfide mineralization. However, sulfides do not occur everywhere within the deposit. In some places ludwigite rocks contain negligible, if any, amounts of sulfides; such an area occurs in lower Shirokiy Log (trench 155), the eighth and other parts of Pad' Rudnichnaya, where ludwigite is altered differently.

The alteration of ludwigite into ascherite and magnetite under hypogene conditions occurs extensively here but to varying degrees. Sample V (Fig. 5), a pseudomorph after long radial ludwigite, is an example.

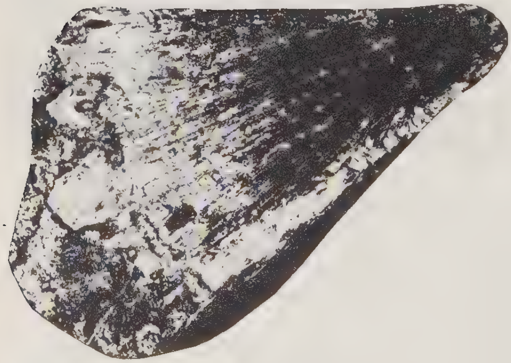

Fig. 5. A pseudomorph after long, radial ludwigite.

Dark -- magnetite and small amounts of ludwigite; light -- ascherite, brucite, hydro-magnesite, and calcite. Sample V. Reduced 30 percent.

Microscopic study of the sample discloses that its central part consists of a pseudomorph composed largely of an ascherite aggregate with enclosed fine-grained, even dust-like, magnetite. Ascherite is partially replaced by similar aggregates of brucite, hydromagnesite, and calcite. There are small relicts of ludwigite and small amounts of chlorite and serpentine (Fig. 6). Ludwigite relicts are not quite fresh. They are partly replaced by limonite in which fine mineral grains can be seen locally; these grains most likely are brucite and possibly hydromagnesite; in the majority of cases iron hydroxide obscures the presence of other minerals.

Fig. 6. Microphotograph of a thin section, sample V.

Dark -- magnetite, small amounts of ludwigite, and limonite; light -- ascherite, brucite, hydromagnesite, serpentine, and chlorite. Sample V. Thin section. Without analyzer. Magnified 20X.

At the margins of Sample V, all the components are replaced by calcite (Fig. 7) except magnetite. The calcite content gradually decreases toward the center of the sample. The calcite replacement of the products of ludwigite decomposition occurs extensively in near surface workings.

We may conclude that ascherite becomes decomposed in the presence of acidic surface waters that extract boron and most likely form orthoboric acid, but hydromagnesium turns into brucite and hydromagnesite, which later may be replaced by calcite.

The relict ludwigite of ascherite rocks and ludwigite of rocks in which ascheritization is negligible become decomposed under surface conditions without turning into transitional boron minerals; boron becomes extracted directly from ludwigite.

The ludwigite alteration process undoubtedly

Fig. 7. Pseudomorph after ludwigite.

Dark -- magnetite and limonite; light -- calcite Sample 3. Thin section. Without analyzer. Magnified 30X.

depends on the chemical composition of the ludwigite itself; the ludwigite isomorphic series ranges from magnesium to pure iron varieties. The available chemical assays of ludwigite from the Zheleznyy Kryazh deposit deomonstrat a considerable range in its composition; however, the data is still inadequate for a detailed discussion.

In conclusion, let us once again touch on the significance of hydrothermal and other penetrating solutions in the decomposition and sulfidization of, and boron extraction from ludwigite. As mentioned previously, in a number of places in the deposit, there is a close association of pyrrhotite with ludwigite. Thereby, two pyrrhotite modifications may occur; the first of these is visible macroscopically. It is granular, and hydrothermal. The second modification occurs in the form of highly dispersed matter enclosed in the products of ludwigite decomposition.

Under near surface conditions, partly altered ludwigite-pyrrhotite rocks become highly oxidized, and carbonized, and their boron is extracted. We may, therefore conclude that the ludwigite decomposition and extraction of boron takes place at least partly in the oxidation zone, in the presence of near surface solutions.

The conditions under which ludwigite becomes decomposed while hydrothermal pyrrhotite remains intact are less clear. None of the sections of sulfide-ludwigite rocks studied (from Zheleznyy Kryazh) show association of pyrrhotite with fresh ludwigite that is not turned, at least partly, into boronless minerals and dispersed secondary sulfides. In other words, in all cases where ludwigite is associated with pyrrhotite, it loses a part of its boron content. This seems to indicate decomposition under hydrothermal conditions. However, the depth of drill holes from which magnetite ore-bearing ludwigite was recovered generally does not exceed 100 meters. Farther down, the drill holes penetrated skarn-magnetite formations without ludwigite or granitoid rocks. Since the zone of oxidation in the deposit of Zheleznyy Kryazh is well developed in near surface workings and along fault zones, surface solutions seem to have reached down to the depth of 100 meters, where ludwigite and the sulfidized product of its decomposition were found.

It seems that the fine-grained inclusions of pyrrhotite in the original ludwigite-pyrrhotite aggregates became oxidized more easily in ludwigite and produced acids that decomposed ludwigite, and gels of iron sulfides gained space. It is known, however, that iron sulfide gel, particularly that of colloidal melnikovite, may be formed under both exogenic and endogenic conditions. Thus, the available data does not permit us to draw a definite conclusion concerning the significance of hydrothermal solutions in the decomposition of ludwigite. Additional data is needed on the state of rocks containing ludwigite and hydrothermal pyrrhotite from such parts of the mineralized zone in which, for one or another reason, oxidation did not occur.

However, the synthesis of the above observations suggests that the ludwigite decomposition and the formation of finely dispersed sulfides and extraction of boron most likely occurred during a late hydrothermal stage.

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DISTRIBUTION AND MECHANISM OF INTRUSTION OF TRAP ROCKS IN THE SOUTHEASTERN SIBERIAN PLATFORM

by

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DISTRIBUTION OF TRAP INTRUSIONS IN THE SOUTHEASTERN SIBERIAN PLATFORM

Structurally, the southeastern part of the Siberian Platform is not uniform; it includes five principal structural elements:

1) Lower Paleozoic structural basin of the Angara-Lena region.

2) Southwestern part of the Viluy basin.

3) Northeastern end of the Baikal fold-zone.

4) Berezov structural basin.

5) Northern slope of the Aldan upwarp.[1]

The local structures in the southeastern Siberian platform controlled the intrusion of dikes and sills; the mechanism of trap intrusions in each of the above structural units has its own characteristics.

The regions in which the sedimentary blanket of the platform is barely deformed and the crystalline basement is close to the surface (northern slope of the Aldan upwarp, where the thickness of the sedimentary blanket according to drilling data ranges from 500 meters at the Tolba River to 1,000 meters near the village of Russkaya Rechka) have dikes generally confined to numerous fault zones. The dikes form wide zones generally trending southeast. Faults (including tension fractures), along which the basic magma was injected, are, according to Yu. K. Dzevanovskiy [5], synchronous with the Post-Cambrian (Variscian) deformation of the Archaean and Cambrian strata.

Parts of the platform, having a peculiar type of folding, complicated structure, and a sedimentary blanket up to 3,000 or more meters thick (the Lena fold zone in the lower Paleozoic subsidence of Angara-Lena [6]), exhibit a specific distribution and manifestation of the trap volcanism.

For example, in the extreme southwestern part of the basin, in the area occupied by thick Upper Cambrian and Ordovician sediments (Upper Lena Basin), trap rocks are very rare. They occur in the elevated, northwestern parts of the basin, in the Angara-Ilim region and in the basin of the Nepa River. Here, largely interformational trap bodies occur between the eroded surface of the "Lena limestone" (Cm_1) or Ordovician and the productive stratum (P_1-P_2). In the intensely folded, lower Paleozoic rocks of the Nepa district, trap sills are absent. Strongly folded Cambrian and Silurian rocks were apparently not suited for intrusion of sills.

In the northern districts of the Angara-Lena basin (Viluy River and its right-hand tributaries such as the Chona, Malaya and Bolshaya Botuobiya Rivers, and others), where the sedimentary blanket is barely folded and relatively thin, trap rocks in the form of both dikes and sills are more abundant. In some cases the trap sills are confined to the contact between the Ordovician and the productive strata (P_1-P_2), and in others occur between the Krivolutsk and Ust'kut layers (O_1) or directly within the Ust'kut layers. The trap sills occupy larger areas and are exposed along the edges of well-shaped mesas. Thick trap sills (100 to 200 meters) occur in the extreme northeastern part of the basin (Nyuy-Viluy Basin) and farther east in the adjacent part of the North Baikalian fold zone -- in the former within the Cambrian and Ordovician beds, predominantly at the base of Cambrian sediments and in the Patomsk complex (Prz). Trap dikes are rare and relatively thin (40 to 60 meters) in both areas and trend northeast.

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[1] We will not discuss details of the above structures, for they are described in the publications of N.S. Zaytsev [6], N.M. Chumakov (1956), and others.

The regions of the lower Paleozoic of ngara-Lena, the depression of Tungusska, e Berezov subsidence, and the northwestern ope of the Aldan upwarp have many phases id a variety of forms of trap intrusions. here are several sequences of sills and ocks formed at various stages of trap trusion. Their form depends on the type tectonism in the areas concerned, and eir number on the complexity of tectonic id related volcanic processes.

In the region of the Berezov subsidence, idely developed trap sills occur at a depth 500 to 2,000 meters.

In the southwestern part of the Viluy asin, a few gently dipping trap dikes are ot related to any known fault zone. Such trusions, we believe, should be explained peculiarities of lower Paleozoic structures this region that plunge due northeast nder the Mesozoic of the Viluy Basin.

RELATION OF TRAP VOLCANISM TO ELEVATIONS OF THE CRUST

Within the above structures, the ages trap rocks, sedimentary, and sedimen- ry-volcanic formations constituting one or nother structure are determined by their storic development. The northeastern argin of the Baikal fold zone[1] and the orthwest of the Aldan upwarp, composed cclusively of old strata (Lower Cambrian, oterozoic, and Archaean), have predomi- intly old (Caledonian?) trap rocks, while e southwestern part of the Viluy basin, e northwestern margin of the Angara-Lena isin and the Tungusska depression, pre- ominantly composed of upper Paleozoic and esozoic rocks (Permian, Triassic, and ower Jurassic), largely contain Permian id Triassic (some post-lower Jurassic) trusions. This does not, however, exclude e presence of younger trap rocks in the rmer areas and older ones in the latter. ich a distribution of trap bodies does not sult from an "erosional cut" but is im- lled by the geologic development, not only the Siberian platform but also of sur- unding regions.

The location of the majority of extensive kes along widely-extended fault zones indi- tes that maximum volcanic activity coin- ded with the periods during which faults ere formed under conditions of tension oduced by elevation but not depression. Thereby, faults -- and frequently the dikes confined to them -- trend parallel to the strike of major folds, and this suggests a definite relation between faulting to folding. For example, in the lower Paleozoic Angara-Lena basin and along its extension, the Berezov basin, folds and trap dikes are controlled by the northeasterly strike of the structures. Also at the northeastern end of the Baikal fold zone, faults and the dikes trend almost latitudinally, in conformity with the strike of folds of the external part of the Baikal zone. The widespread dikes of northeasterly strike in the area of the northern slope of the Aldan upwarp are also possibly related to the structure of the region.

The present data on the structures within the southeastern Siberian platform confirm the assumption concerning the relation of intrusive activity to elevations of the crust. The extensive occurrence of presumably old trap rocks at the northeastern end of the Baikal fold zone (and possibly within the Baikal mountainous region which, early in the lower Paleozoic, joined the platform) on the northwestern slope of the Aldan upwarp, and in the area where the latter joins the Berezov depression, is consistent with the history of development of these regions. The anticlinal structure of the northern slope of the Aldan massif was, according to K.K. Zelenov, formed during the Early Cambrian. By the end of the Early Cambrian, according to him, elevation of the anticlinal structure ceased (or slowed down).

As far as the Baikal fold zone is concerned, there are convincing facts [11] pointing to a continuous elevation of this zone from Late Silurian to the Jurassic inclusive, namely, the long duration of tectonic movement, which we believe to have controlled the consecutive injection of trap intrusions in the territory under discussion. Absence of old trap rocks in the northwestern part of the lower Paleozoic Angara-Lena basin and in the Viluy basin is apparently related to the fact that the region between the mountainous district of Baikal and the crystalline massif of Anabar was a zone of subsidence. There are no exposures of Precambrian rocks; large areas are occupied by younger, lower Paleozoic marine sediments (mostly Silurian; [11]).

In the upper Paleozoic and Mesozoic the situation changed. The maximum volcanic activity moved due west into the region of the Tungusska depression, while in the southeast Siberian platform the diminishing volcanism formed dikes, largely confined to faults, in places of great extension (up to 230 kilometers long).

The region of the Tungusska depression

[1] The Baikalian folding caused the develop- ent of joints in the platform during the lower leozoic [11].

was largely a region of subsidence during the upper Paleozoic (Hercynian) diastrophism. Only in the late Paleozoic and early Mesozoic did it begin to rise; its axial part became broken by deep faults and a net of smaller fractures which permitted the trap magma to rise up to the surface or close to it. The complexity of the structure in the Tungusska depression is caused by subsidence of some of its parts while the others were uplifted, consequently the trap volcanism developed differently in different parts of the depression. The large lower Paleozoic anticlines within the Tungusska depression (the Chadobetsk and other uplifts) substantiate the heterogeneous structure and consequently the uneven thickness of the lower Paleozoic sedimentary blanket, as well as the differing direction and intensity of movements that took place in the lower Paleozoic within the contemporary boundaries of the Tungusska depression. This permits one to assume that the trap volcanism in the lower Paleozoic (Caledonian?) developed only in certain places and most likely was not intensive. The local trap intrusions might possibly have been injected synchronously with the emplacement of igneous rocks at this time in the southeastern Siberian platform, at the northeastern end of the Baikal fold zone and within the western slope of the Aldan upwarp.

The trap magma invaded the northwestern part of the lower, Paleozoic Angara-Lena basin, most likely during the principal stage of trap intrusion in the Tungusska depression, during the late Paleozoic or early Mesozoic. This is indicated by the similarity of the trap rocks of the Angara-Lena basin and the Tungusska depression and to a certain degree by the complete absence of trap sills in the lower Paleozoic formations within the northwestern part of the Angara-Lena basin.

The areas where different structural elements join each other, such as the Tungusska depression and the lower Paleozoic Angara-Lena basin, the Berezov basin and the Aldan upwarp, etc., were extremely mobile zones, where the great tension, caused by the opposite movements of adjacent blocks, existed for long periods. This mobile state controlled the localization of the repeated trap volcanism in the zones concerned. The location of trap rocks within elevated areas but not in basins has been repeatedly mentioned in the geologic literature [7, 9, 16]. The elevated areas, like any arch, were evidently most favorable places for intrusion by trap magmas, especially if we keep in mind that even during subsidence (formation of depressions) the top of the crystalline basement, according to N.S. Shatskiy [17], remains generally convex upward.

The relation of magmatism to the epochs of elevation of any region, and the repeated

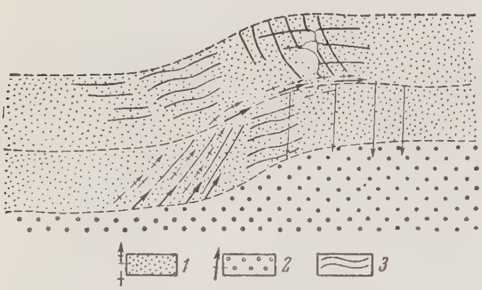

Fig. 1. Scheme of an Initial Stage of a Steep Flexure in a Platform (after A.A. Polkanov, 14)

1 -- Sial (dotted) and the direction of flow of molten granite in it (arrows).
2 -- Sima and the flow of basic magma along a stretched flexure (thick arrows)
3 -- Compressed sections. Inclined solid lines -- tension fractures due to flexure; horizontal solid lines -- shear fractures due to flexure. Vertical arrows show the downward flow of the lower part of the sial owing to the intrusion of basic and acidic magmas along the central shear plane (location exchange after F. Yu. Levinson-Lessing).

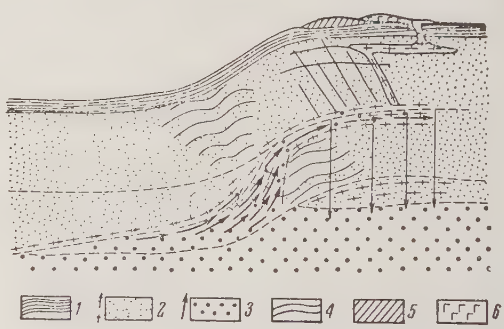

Fig. 2. A Sketch of a Steep Flexure in a Platform and the Formation of Abyssal Reservoirs of Basic and Acidic Magma. The stage accompanied by the magmatic invasion of a platform (after A.A. Polkanov, 14).

1 -- Sedimentary and volcanic formations on the platform; 2 -- Solid (dotted) and selectively molten sial and direction of flow (thin arrows); 3 -- Sima, thick arrows show the direction of flow of the basic magma; 4 -- Compressed sections of the flexure; 5 -- Basic lava flow; 6 -- Acidic lava flow.

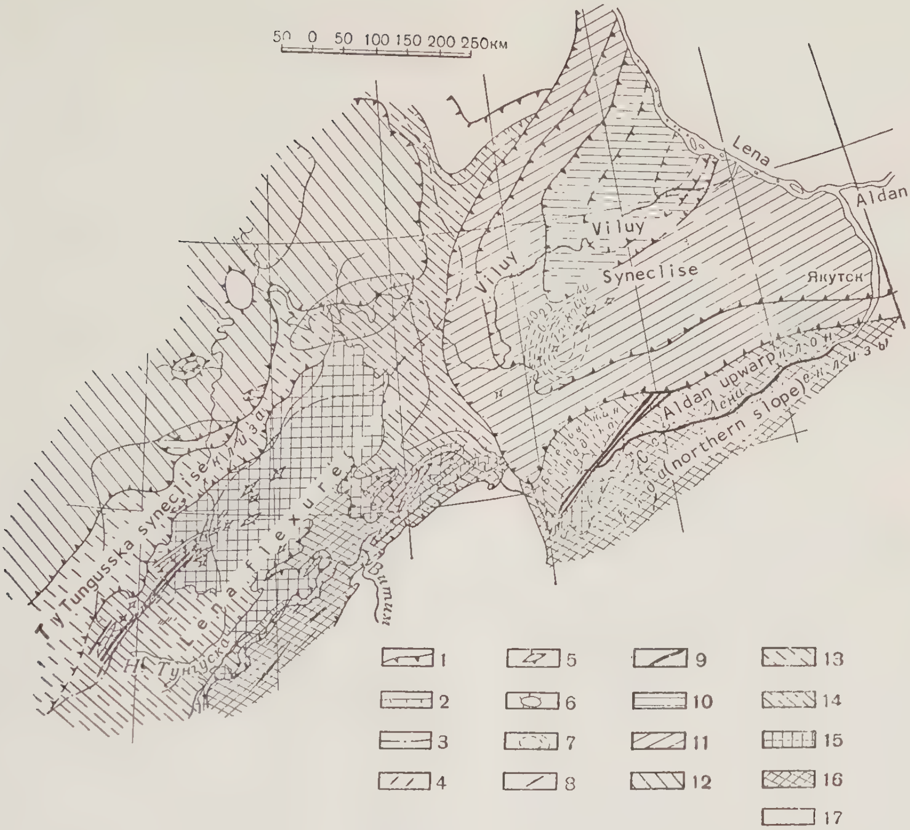

Fig. 3. Disposition of the Zones of Magnetite Mineralization in the Southeastern Siberian Platform.

1-boundaries of structural levels; 2-probable structural lines; 3-boundaries of broadly-developed trap rocks; 4-linear, bent anticlines; 5-brachyanticlines and arch-shaped elevations; 6-obscure anticlinal elevations; 7-gravity anomalies; 8-faults; 9-zones of magnetite mineralization; 10-Upper Cretaceous; 11-Jurassic and Lower Cretaceous; 12-Upper Permian and Triassic; 13-Carboniferous and Permian; 14-Ordovician and Silurian; 15-Upper Cambrian; 16-Lower and Middle Cambrian; 17-Proterozoic.

location of trap bodies in axial parts of anticlines (Naman and Sinyaya river basins)[1] indicate the great significance of vertical movements and stretching during magmatic processes. The number, length, and thickness of dikes reflect to a certain degree the intensity of stretching during the elevation of the region concerned. The localization of trap rocks in zones of intense disturbance, fault zones, is conventionally recognized.

Thereby, we are inclined, in accord with the concept of N.S. Zaytsev [8] and P.E. Offman, to consider the zones where upwarps join depressions to be zones of maximum permeability for intrusive trap magma, for they are the most favorable large fault zones. Such zones in geosynclines are called deep breaks by A.V. Peyve [12] and the term can possibly be applied to platforms.

The sketch suggested by A.A. Polkanov for steep flexures within a platform and applicable in our case, we believe, explains the general localization of intrusions in the zones where two opposite structural types (depressions and upwarps) join each other

[1] The location of trap bodies in elevated areas was recognized here by numerous structural studies by both geologic and magnetometric methods.

(Figs. 1 and 2).

According to A.A. Polkanov, flexures accompany deep tension faults, along which a swarm of dikes may be intruded or along which sills may be channelized. The zones along which the opposite structural types join also serve as channels of postmagmatic solutions and frequently turn into large deposits of useful minerals. For example, the zone where the Tungusska depression joins the Nepa upwarp (within the lower Paleozoic Angara-Lena basin), a number of iron ore deposits form a belt trending northeast (the Angara-Ilim and Nepa group of iron ore deposits). Another series of iron ore deposits (Daban, Biryuk, Dirin-Yuryakh, and others) form a northeast-trending belt along the zone where the Aldan upwarp joins the Berezov basin (Fig. 3).

CHEMICAL AND MINERAL CHARACTERISTICS OF THE PRINCIPAL VARIETIES OF TRAPS

On the basis of chemical and mineral composition of trap rocks known within the above structural elements in the southeastern Siberian platform, it appears that normal trap rocks, dolerites and olivine (in some cases, picrite) dolerites with ophitic and poikilophitic structures prevail in the northwestern part of the lower Paleozoic Angara-Lena basin and in the zone where it joins the Tungusska depression, and at the latter's eastern margin. Doleritic porphyries,[1] subalkaline dolerites, ataxic porphyries, and palagonitized olivine dolerites are also present. The latter two types of trap rock are considered to be post-Lower Jurassic, but the dolerite, olivine dolerite, and dolerite porphyry are dated as Permian or Triassic. A few Permian Triassic trap rocks are present in the northwestern part of the Viluy depression, the Berezov basin, at the northeastern end of the Baikal fold zone, and on the northern slope of the Aldan upwarp.

Palagonitic, vuggy dolerite forms a special province, located largely in the northwestern part of the Viluy depression. They are pre-Lower Jurassic and apparently were formed at the beginning of the Mesozoic (Triassic) stage of volcanism. The northeastern end of the Baikal fold zone and partially the northwestern slope of the Aldan upwarp, and the zone along which the latter joins the Berezov basin, are largely occupied by trap rocks sharply different from the above trap rock varieties, according to both composition and intensity of metamorphism. Here amphibolized, biotitized, and chloritized olivine diabase, pegmatoid-like diabase monzonite, and amphibolized olivine microdiabase, which we consider to be pre-Upper Permian (Caledonian?) predominate.

The Berezov sagging and the northern slope of the Aldan upwarp are occupied by extensive leucocratic trap rocks, such as leucodolerites and quartz dolerites, which, on the basis of a number of criteria, are believed to be of late Hercynian (Permian or Triassic) age. The above varieties of trap rock can hardly be correlated by their chemical composition because of the absence of chemical assays from a number of regions, such as the northern slope of the Aldan upwarp and the northeastern end of the Baikal fold zone. But numerous assays of trap rocks from other structural regions permit us to draw the following conclusions: the trap rocks developed within the lower Paleozoic Angara-Lena basin and along its boundary with the Tungusska depression have average compositions close to that of plateau basalts, which, according to G. Washington, are basalt flows that did not reach the surface. The similarity is expressed particularly in the ferrous iron content and in the FeO:MgO ratio, which is a very characteristic indicator of this group of rocks. For example, in the world-wide plateau basalt, this ratio is 1.73; in the trap rocks near the Angara River, 1.50; in the trap rocks of the middle Viluy River, 1.40. The alkaline and silica content also confirms the similarity; the differences range from one to two percent.

The group of palagonitic[2] vuggy dolerites, whose coefficient "a" (according to the classification by A.N. Zavaritskiy) differs greatly (in some cases reaches 10.5 or even 13.2) from that of a normal trap magma. Unlike the normal dolerite of the earlier phase, these dolerites are considered to be of the latest Permian or Triassic phase of the trap intrusion and are rich in Fe_2O_3, MgO, and alkalines in which the K_2O content exceeds that of Na_2O in a number of cases.

The palagonitic dolerite contains up to 11 percent Fe_2O_3 in places, whereas in the majority of normal trap rocks this content varies from 3 to 5 percent. The total

[1]After submitting the article, the author reviewed the trap rock nomenclature and recognized that the term "microdolerite porphyry" would fit the rock better than "doleritic porphyry" and the term "ataxid microdolerite" should be applied instead of "ataxic porphyry."

[2]Palagonite is a remaining magmatic gel, frequently rich in alkalines, hardened, and crystallized to a variable extent.

alkaline content in palagonitic dolerite usually ranges from 3 to 4 percent, sometimes reaches 6.5 percent, but in the majority of normal dolerite it does not exceed 2.5 to 3 percent; hence $K_2O:Na_2O$ in the palagonitic dolerite reaches 3:1, but in normal dolerite the ratio is reversed.

Palagonitic dolerite contains less SiO_2, TiO_2, and FeO than normal dolerite; for example, the SiO_2 content in normal dolerite ranges from 40 to 50 percent, but in palagonitic dolerite the silica content never reaches 48 percent, and in some cases drops to 37 percent. The FeO content is also very indicative; in palagonitic dolerite it most frequently ranges between 3 and 6 percent, in normal dolerites between 8 and 10 percent.

The peculiarities of the chemical composition are reflected in the mineral composition of the palagonitic dolerite; alkaline minerals, chiefly potassium minerals, constitute up to 25 percent of the volume of the normal dolerite, whereas in palagonite their content remains between 6 and 7 percent. The prevalence of magnesium over iron leads to the formation of pyroxene such as clinoenstatite-diopside, or even more frequently to the clinoenstatite-pigeonite series and to the nearly complete absence of iron-rich olivine. Olivine of hortonolith type occurs sporadically.

Table 1 compares the average compositions of palagonitic and normal trap rock and illustrates the high H_2O, K_2O, and MgO content of the latter.

The assays also show a slight increase in the fluorine content in palagonitic dolerite

Table 1

Components	Average of 13 assays of palagonitic dolerite (after V.I. Gon'shakova); weight in percent.	Average of 20 assays of normal trap rocks (after A.P. Lebedev); weight in percent.
SiO_2	45.03	48.50
TiO_2	1.69	1.42
Al_2O_3	16.32	15.75
Fe_2O_3	7.01	3.43
FeO	5.94	8.88
MnO	0.09	0.16
MgO	6.43	5.62
CaO	8.65	10.69
Na_2O	2.35	2.18
K_2O	1.79	0.69
H_2O	3.90	2.60

relative to that in other trap rocks. There is 0.03 to 0.10 percent F in palagonitic trap rock, but the F content of the three assayed normal traps averages 0.02 percent.

In view of the geologic position of palagonitic trap rock, its occurrence in the form of independent intrusives, in places constituting certain "provinces" (e.g., the western part of the Viluy depression), we may assume that the magma of higher K, Mg, and water content, of which the palagonitic vuggy dolerites were formed, was separated from the original magma of normal basalt at great depth as a result of magmatic differentiation. The separation of the "palagonitic" magma from the normal ones is possibly a result of magmatic evolution that led to the concentration of light-fluxing components and first of all of water in the remaining molten magma. This younger age of the palagonitic trap rocks is another bit of evidence in favor of this assumption.

Despite the fact that the trap rocks of the northeastern end of the Baikal fold zone and the northwestern slope of the Aldan upwarp were not assayed, their mineral composition (presence of quartz, potassium, feldspar, amphibole, biotite, and other minerals) and structure permit one to believe that hybridization[1] at great depth was a decisive factor in their formation, and in some cases led to slightly acidic trap varieties. This assumption is consistent with the geologic characteristics of the two structural regions.

As previously mentioned, these structures are affected by shallowness of the crystalline basement that in some cases was a floor (perhaps a container) of the magmatic chamber in which a basic magma, reacting with the crystalline basement, was turned into a trap magma. Consequently, the resulting trap rocks contain the above minerals not typical of basic magma. The intense autometamorphism, the presence of such minerals as sphene and apatite -- especially abundant in contact aureoles and in postmagmatic (hydrothermal) derivatives of trap intrusions -- also suggest a hybrid origin of the rocks. The hybridization of a normal trap magma of basaltic composition at great depth could have proceeded as suggested in the schemes by A.A. Polkanov (Figs. 1 and 2).

The much greater depth of the crystalline basement in the lower Paleozoic Angara-Lena basin and in a number of localities in the

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[1] A.P. Lebedev mentions extensive hybrid trap rocks in the western part of the Tungusska depression 7 .

Tungusska depression, along with a number of tectonic characteristics of these regions (the presence of faults), was perhaps the reason for the general development of normal (basaltic) trap rocks in these regions. The location of the magmatic chamber within a thick sedimentary layer composed of lower Paleozoic carbonate layers most likely controlled the formation of subalkaline derivatives of the trap magma.

MECHANISM OF TRAP INTRUSION

Having outlined the general features of trap occurrences in the southeastern Siberian platform, let us review certain characteristics of the mechanism of trap intrusion with the example of the trap dikes and sills described in this study.

First of all, let us review the concepts of earlier investigators on the mechanism of trap intrusion.

F. Yu. Levinson-Lessing [8] is one of the earliest investigators who expressed his view on the mechanism of emplacement of trap sills. He suggested that trap magma passively filled in the space, formed "as a result of gradual subsidence of the bottom of intrusive bodies in the course of magmatic intrusion." Later, in 1941, Yu. K. Dzevanovskiy [4] expressed another view on the subject. He believes sills require vertical fractures that serve as feeding channels. Sedimentary layers whose bedding planes may easily be opened by an intruding magma contribute to lateral expansion of the magma, i.e., to the formation of sills. He writes, however, that a magma injected "under pressure" may form only small bodies, while large bodies can be formed as suggested by F. Yu. Levinson-Lessing. On the basis of a detailed study of the Hoglandian-Iotnian magmatism of the Baltic shield, K.O. Kratz and A.A. Polkanov (1953) draw the conclusion that the lateral expansion of magma, as a result of which sills are formed, most likely took place because of difference in magmatic pressure and the weight of the overlying rocks. If the pressure of the ascending magma overcomes the weight of the overlying stratum, the magma expands laterally.

The observations by A.P. Lebedev [7] in the central part of the Tungusska basin suggest an active role for the trap magma in the formation of sills. The author believes that magma moves forward like a "wedge" along bedding planes, actively pushing aside and breaking the rocks. P. Ye. Offman [10] is not inclined to consider magmatic activity to be a significant factor in solving the space problem. He rejects the physical action of trap magma upon the enclosing rocks as a significant factor and emphasizes the contrary -- the absence of crushing or bending of beds near trap intrusions.

M. G. Ravich and L. A. Chayka [15], who studied various trap intrusions in the fold zone of Taymyr, assume that a tremendous magmatic chamber was formed gradually, most likely because of subsidence of part of the geosyncline in the course of sedimentation, during which magma and the sedimentary strata have continuously exchanged places.

Thus, the existing concepts of the mechanism of trap intrusion can be combined into two groups: the first group of investigators considers the intruding magma to be passive; the other group believes that faulting and the active magma itself are the factors leading to trap intrusion.

Our studies of trap rock in the southeastern Siberian platform permit us to conclude that the mechanism of trap intrusion is determined by magmatic activity and the geologic make-up of the region concerned (composition and thickness of the sedimentary cover, structures, etc.).

The study of trap dikes in the southeastern Siberian platform discloses that some of them concordantly filled in "open" faults without causing any deformation near the contact (l. g., on the northern slope of the Aldan upwarp), and others are discordant to the bedding planes of the enclosing rocks and affected them thermally; in other words, the trap magma was actively intruded (the southwestern part of the Viluy depression, the lower Paleozoic Angara-Lena basin, and the Berezov basin).

On the northern slope of the Aldan upwarp, the crystalline basement is close to the surface and the sedimentary sequence consists of Lower Cambrian carbonate rocks. In this region the thickness of dikes does not exceed 100 meters and in places drops to 5 or 10 meters, despite great lateral extension, in places reaching hundreds of kilometers. Here dikes are commonly confined to zones of tectonic disturbance, some of which are 2 to 3 kilometers wide and as much as 200 kilometers long. Such zones striking northeast contain a series of en echelon dikes (F.G. Gurari). Similar trap dikes occur broadly in the basin of the Lena River between the mouth of the Biryuk River and the village of Tit-Ary. The contacts of dikes and their location within narrow zones indicates that the magmatic intrusion was channeled along

"open" cracks.

A quiet injection along cracks and fractures by trap magma is evident in both districts because of the complete absence of structural dislocations at the contact. The well-foliated Lower Cambrian limestones (motley layers Cm_1) show this clearly. For example, on the right bank of the Lena River, opposite the village of Sinsk, three vertical trap dikes striking 30° northeast are exposed. Dikes have very clear and sharp contacts against the enclosing Lower Cambrian limestones that lie almost horizontally (dipping one degree or less south). The foliation of the limestones is very clear because of interbedded light grey and brick-red layers 15 centimeters to one meter thick. The layers can be traced for hundreds of meters or even kilometers. The limestone beds are not disturbed at the contact with the trap dikes, nor are they displaced. The composition of the dikes is very uniform, if thin aphanitic zones are disregarded; they do not show any traces of autobrecciation or contain any xenoliths suggesting an active magmatic intrusion into "open" cracks.

In analyzing the complicated geology of the zone along which the Berezov basin joins the northwestern slope of the Aldan upwarp, we notice numerous branchy-folds and archs of northeasterly strike, faults along which movement has occured, and trap intrusions along these faults. A new type of trap intrusion, different from those described above is present here.

These trap bodies are controlled by the structure of the sedimentary blanket. But the steep dip of the intrusives indicates that they cut the enclosing rocks. The "lifting up" of enclosing layers by the trap magma at the contact points to active magmatic intrusion. Thereby, the enclosing rocks were disturbed only in the hanging wall, while the foot walls remained undisturbed. This fact can possibly be explained by the unequal velocity of the magmatic flow in different parts of the intrusive. The top parts of the magmatic flow seem to have been most active because of the higher content of components that lowered the magmatic viscosity and increased the velocity of flow. That is, this apparently caused a more extensive physical and chemical alteration of the surrounding rocks and lifted the enclosing rocks near the top but not near the floor of the intrusive magma. Such cases may be observed in the lower basin of the Naman River, near the village of Et-Kyol', near Chokur Creek, and elsewhere.

In Lower Cambrian sedimentary rocks at the Chokur River there is a large trap dike exposed, 125 meters thick, striking northeast (35°). The nearly latitudinal Cambrian limestone layer dips 15 to 20° NNW. The dike strikes 35° NE and dips 78° NW. The enclosing rocks of the hanging wall change their bedding planes within a 7 meter wide zone; their strike changes from latitudinal into 35° NE, i.e., it approches that of the dike; then the dip becomes steeper (45 to 50° NW).

At the foot wall of the dike, the bedding planes of the country rock are virtually not disturbed if a slightly steeper dip (20 to 25° instead of 15°) is disregarded. Similar phenomena were noticed near the village of Et-Kyol'. A thick (100 meter) dike-like body cuts the Upper Cambrian carbonate rocks, the limestone-marl layer Cm_3 that strikes northeast and dips 45° south-southeast. The enclosing rocks at the hanging wall of the dike are uplifted and dip, concordantly with the intrusive body (80° SSE).

The magma apparently was injected into a weakened brecciated zone, moving forward like a wedge. The wedge-like intrusion gained the space by lifting up the surrounding rocks, partially increasing their density, and in places assimilating the country rock (Figure 4). For example, near the lower Nepa River, the increased density of Lower Cambrian rocks at the trap dike is expressed in the form of a foliated zone, 5 to 7 meters wide, where limestones became finer grained.

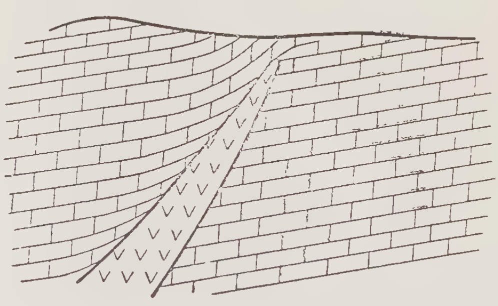

Fig. 4. Uplifting of beds at the Hanging Wall of an intrusion.

In the basins of the Viluy and Bolshoy Patom Rivers, intense brecciation of traps due to injection of younger trap magma occured (ataxic porphyry in the Viluy basin and amphibolized olivine microdiabase at the Bolshoy Patom River).

A wedge-like active magmatic intrusion of trap rock into sedimentary or other intrusive rocks is well-pronounced on a "microscopic" scale. For example, at the

left shore of the Lena River, near the Tyunichnyi spring, there is an intrusive diabase cut by numerous, thin porphyry dikes terminating in a wedge shape. The thin dikes, confined to cleavage surfaces of the diabase, are from one to 50 centimeters thick (Fig. 5). Their contacts are sharp except for a few places where zones of gradual transition are present. In places, porphyry was injected not only along cleavage surfaces but also along microfractures occurring in the diabase.

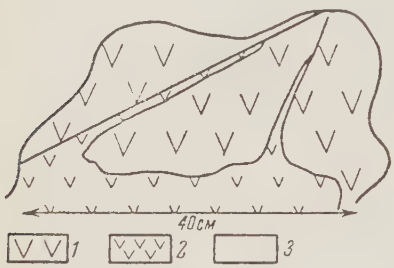

Fig. 5. Wedge-like intrusion of a diabase dike by a later trap magma along fractures.

1-diabase; 2-porphyry; 3-fractures.

The intrusion of a diabase dike by a later trap magma along microfractures is accompanied by partial "melting" assimilation, and recrystallization of the diabase at intersections with trap veinlets, which consequently become thickened. The recrystallization of diabase is evident in diabase inclusions within prophyry veinlets. The inclusions show gradual transitions and altered structure near the contact with the porphyry. The microscopic studies disclosed numerous fine grains of greenish pyroxene and ore minerals forming a wall between the two intrusive bodies. This pyroxene is optically quite different from the large pyroxene grains of the diabase and, on the basis of its composition, it hedenbergite ($En_5 Wo_{20} Fs_{75}$; cNg = 47°; 2V = +58°).

The coarse-grained pyroxene of the diabase is pigeonite-augite ($En_{35} Wo_{30} Fs_{35}$; cNg = 40°; 2V = +40°). Some large grains (the composition of which is $En_{30} Wo_{42} Fs_{28}$; cNg = 380°; 2V = +46°) are commonly preserved among fine grains of the new pyroxene and ore minerals; they indicate an incomplete assimilation of the diabase (Figures 6 and 7). Besides, fine-grained aggregates of the newly-formed pyroxene and ore minerals generally contain isometric or irregularly-shaped grains of plagioclase, the composition of which can hardly

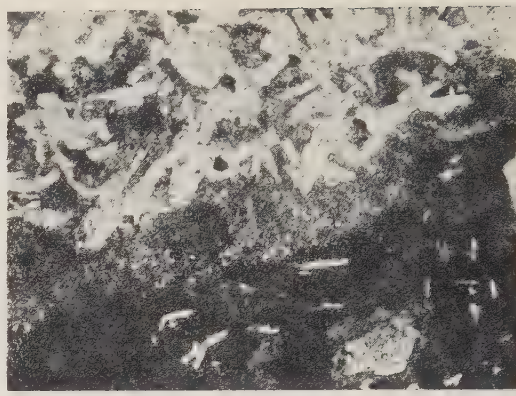

Fig. 6. Border composed of fine-grained greenish hedenbergite at the diabase porphyry contact.

Magnified 46X, without analyzer.

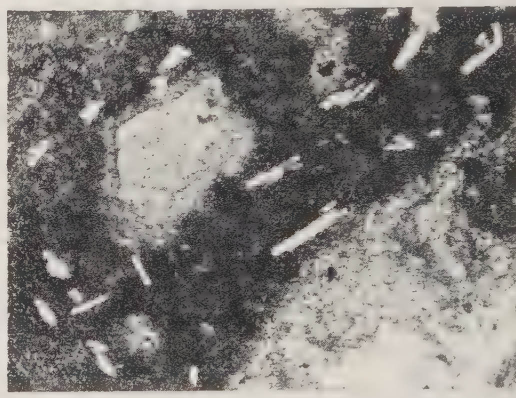

Fig. 7. Relict grains of pigeonite-augite (of the diabase) at the diabase porphyry contact.

Magnified 70X, without analyzer.

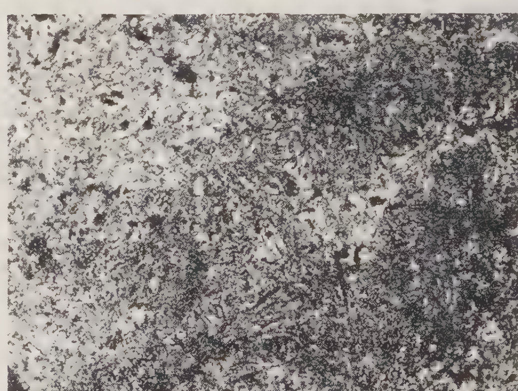

Fig. 8. Porphyry of ataxic structure near the diabase contact.

Magnified 70X, without analyzer.

be determined because of their small size.

The forms of the minerals constituting the wall between the two intrusive bodies and their intercalations are typically diablastic and granoblastic, in places passing into poikiloblastic and sieve-like structures. Farther from the contact, porphyries have fibroblastic, sheaf-like structures with an irregular, ataxic distribution of minerals (Fig. 8). Near the contact, pyroxenes are amphibolized and chloritized, indicative of metamorphism in the presence of considerable amounts of water. The similarity of porphyries and diabases should not lead to the development of rocks of other, even transitional composition, at the contact; the transitional zones usually indicate melting and hybridization of rocks. However, the above transformations, participation of a gas phase in the transportation of the magmatic material to the contact and pyroxene and ore mineral accumulations along the contact indicate that the trap magma actively influenced the readily solidified diabase, indicate the recrystallization of the diabase, and possibly indicate assimilation. We can hardly speak of melting, for the temperature could hardly be adequate for that; consequently, if hybridization of rocks took place, this could only be a result of contact petrogenesis, which is known to be extensive in the western part of the Viluy depression.

The dike-like, predominantly gently dipping bodies of vuggy palagonitic traps, not confined to definite fault zones, contain numerous xenoliths of surrounding rocks and are extremely variegated in their structure and texture. They show vuggy, ataxic, pegmatoid, doleritic, and other structures and textures. Some trap bodies are bedded or foliated, i.e., they consist of alternating vuggy and normal trap layers. The foliation is usually parallel to the contact and conforms with the orientation of elongated xenoliths which are strictly parallel to the contact (their positions frequently indicate the form of intrusives and their depths).

The vuggy texture of dolerite beds rich in palagonite [3] seems to be caused not only by the presence of a peculiar palagonitic substance rich in water disseminated in magma or separated in the form of "drops," but also by assimilation of resurgent matter of the surrounding rocks and xenoliths by the trap magma. Near xenoliths, dolerite is frequently rich in secondary minerals (predominantly zeolites and carbonate) that fill in vugs and produce a texture resembling that of conglomerate.

The great activity of the trap magma is clearly indicated by numerous bodies of ataxic porphyry that occur along the eastern margin of the Tungusska depression and are confined to an area occupied by the productive stratum of the Tungusska complex.[1] The complex is nearly horizontal. The ataxic porphyries are the only steeply dipping, discordant intrusive bodies, i.e., dikes, stocks, and necks; their thickness in cross section rarely exceeds 100 to 150 meters and more commonly ranges from 50 to 75 meters (Fig. 9).

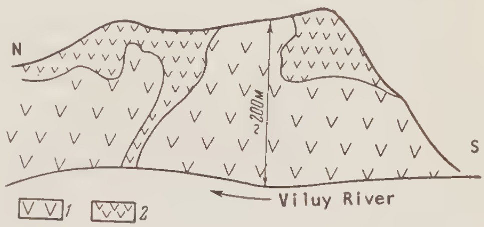

Fig. 9. The ataxic porphyry-type of intrusion into dolerite.

The right bank of the Viluy River between the rapids of Labykhtallakh and Challarattakh, exposure 68. 1-dolerite; 2-ataxic porphyry.

These porphyries contain various xenoliths, such as vein quartz and carbonate rocks most likely of lower Paleozoic or Proterozoic age; however, dolerite porphyries whose composition and structure are similar to those of enclosing porphyries prevail among the xenoliths. The majority of the xenoliths are irregularly oriented except for those present in the contact zone, where they parallel the contact. This indicates that the intrusives were injected under high pressure into narrow fractures or channels.

The structure of the rock is not uniform because of an irregular, spotty distribution of the enclosed clastic material (rock fragments and fragmental mineral grains) and the nonuniform development of hornfels at the expense of both the clastic material and the surrounding mass. The relatively uniform composition of the fragmental material (xenoliths of exotic rocks constitute only a small percentage) and the similarity of its composition to that of the enclosing rock, as well as the simplicity of the process leading to hornfels, permit us to consider the ataxic porphyry to be a rock formed from a mobile basic lava flow repeatedly through the same channels. The magma was so active that it penetrated the nearly horizontal sediments of the Tungusska complex cutting through the enclosed dolerite sills and bringing up xenoliths of exotic rocks from greater depths.

[1] It is possible that similar rocks also occur in other parts of the Siberian platform.

The magmatic injection into one or another area of the platform was to a certain degree controlled by the widespread fracturing of the crystalline basement and the sedimentary blanket at the beginning of the ataxic porphyry intrusion.[1]

The intrusion of sills was determined by the same factors under which the trap dikes were formed, namely, by the active magma and the geologic environment; the sills became confined to weak, most pliable beds of the country rock. Large trap sills, 100 to 200 meters thick, were selectively confined to slightly folded, nearly horizontal sedimentary rocks,[2] but thin bodies (25 to 40 meters) seem to have been capable of invading folded sediments dipping 35 to 40 degrees (Lena basin near the mouth of the Nyuy and Bolshoy Patom Rivers, etc.).

Like dikes, trap sills gained space, moving like a wedge. Thereby, the magmatic flow differentially invaded bedding planes, frequently forming thickenings; the magma squeezed parts, displaced enclosing rocks both vertically and horizontally, and became split into branches before dying out. The wedge-like movement of the magmatic mass along bedding planes, which resulted in the formation of sills of great thickness and lateral extent, indicate the great activity and mobility of the trap magma. Like dikes, sills seem to have been intruded, into places breaking them, especially near the contacts; the magma in places assimilated the country rock, as indicated by relicts of surrounding rocks and minerals near the contact. These facts were confirmed by deep drilling of the Del'gey Oil Exploration Office, Yakutian A.S.S.R. For instance, two rotor drill holes at the right shore of the Lena River, near the village of Del'gey, penetrated five layers of trap sills confined to the contact of rock salt beds with carbonate sediments of the Lower Cambrian. Near the trap contact, the rock salt is recrystallized into coarse crystalline aggregates showing traces of having been subjected to strong pressure. The salt beds apparently were the most pliable plastic beds and were easily attacked by the invading trap magma. The thickness of the sills ranges from 7 to 85 meters.

[1]The ataxic porphyries forming large independent bodies at the eastern margin of the Tungusska depression are believed to be post-Lower Jurassic [1].

[2]The thick sills, enclosed in intricately folded Lower Cambrian sedimentary rocks of the zone where the Angara-Lena basin joins the Baikal fold zone and in the margins of the latter are considered to be the oldest trap rocks in the platform (Caledonian?).

Table 2 shows the depths and thicknesses of trap sills penetrated in rotor holes of the Del'gey Oil Exploration Office.

The correlation of trap sills[3] discloses that the sill 85 meters thick intersected in Drill Hole 2 corresponds in composition and structure to four sills totaling 71 meters in thickness penetrated in Drill Hole 1. The top of the first sill penetrated in Drill Hole 2 is almost at the same level as the top of the first sill penetrated in Drill Hole 1, and the bottom of the first sill penetrated in Drill Hole 2 is on the same level as the bottom of the fourth sill penetrated in Drill Hole 1. Both drill holes are located on a slope of an arch, near its axis, and their mouths are at about the same elevation (Fig. 10. The elevation difference at the surface is almost compensated by the difference in the positions of bottoms and tops of the sills penetrated in Drill Holes 1 and 2, at about the same depth. This relationship permits one to assume that the magmatic flow occurred in the direction of Drill Hole 2 to Drill Hole 1. Within a distance of 2,250 meters[4] the sill is diminished 14 meters in thickness and is divided into four sills. Keeping in mind the positions of the two drill holes, the depths of the sills, and their location in an arch-shaped structure, the magmatic flow was probably controlled by the structure and was directed down the dip of the limbs, in this particular case due southeast (some insignificant deviations can be seen in Table 2 and Fig. 10).

The second sill penetrated in Drill Hole 2 dies out before reaching Drill Hole 1; this may be caused by its small thickness (10.7 meters) or interpreted as the result of diminished magmatic activity and increased density of surrounding rocks due to intrusions of the four previously-mentioned sills. The same considerations are applicable to the fourth sill penetrated in Drill Hole 2 but absent in Drill Hole 1.

The third sill, 61.1 meters thick, penetrated in Drill Hole 2 corresponds in depth to the fifth sill penetrated in Drill Hole 1, where it becomes 74 meters thick. Thus, the magma may have thickened prior to its drying out.

Despite the location in the most incompetent layers (salt beds), local thickenings and vertical displacements, the large extent of

[3]Samples from all the sills were taken and sent to us by resident geologist R. F. Gugol', to whom the author expresses his gratitude.

[4]The distance between Drill Holes 1 and 2.

Table 2

Number of Trap Sills	Drill Hole 1	Thickness in Meters	Number of Trap Sills	Drill Hole 2	Thickness in Meters
1	538.0-545.0	7	1	546.0 - 631.05	85.0
2	561.0-577.5	16.5	2	668.05- 679.75	10.70
3	580.5-602.5	22	3	888.40- 949.50	61.10
4	607 -632.5	25.5	4	1894.5 -1948.0	53.5
5	880 -954	74			

the sill suggests the great mobility and activity of the trap magma, its capacity to move for long distances (more than 2 kilometers). Splitting of the flow into a number of "tongues" and the decrease in the total thickness indicate a wedge-like invasion. If the magmatic flow was from Drill Hole 2 to Drill Hole 1, due south, its feeder channel was apparently somewhere north of Drill Hole 2 and possibly near the zone where the Berezov basin joins the northwestern slope of the Aldan upwarp.

Thus, according to our data, the mechanism of trap intrusions cannot be interpreted by a single theory. The hypothesis suggested by F. Yu. Levinson-Lessing, that trap magma occupies space passively, may be applicable only in particular cases, such as large intrusions, described by M.G. Ravich and L.A. Chayka [17] or differentiated trap intrusions in the fold zone of Taymyr.

The principal and decisive factors in the mechanism of trap intrusions are, we believe,

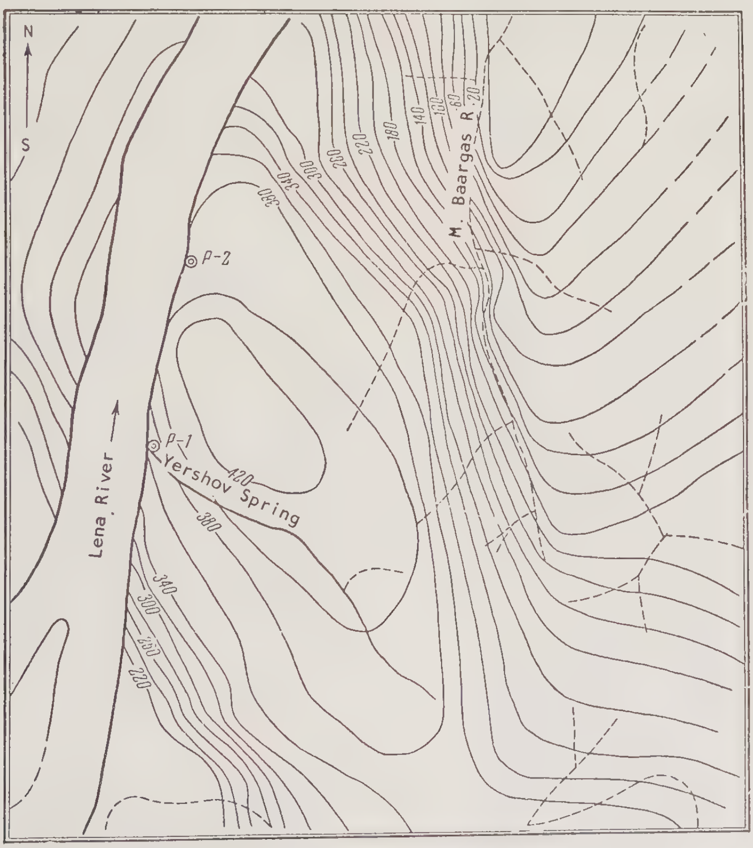

Fig. 10. Structural Map of the Del'gey Exploration Area
(Constructed on the roof of the Ust'kut Formation)
Scale 1:50,000. Constructed by A.K. Bobrov and M.L. Kokoulin, 1952

the tectonic features of the upper and partly of the lower structural levels, the mobility of the trap magma itself that in some cases led to uplifting of the country rock and perhaps to an increase in their density, and in other cases it gained the space by "melting" and assimilating the enclosing rocks. In places, the enclosing beds apparently became bent, as during the formation of salt domes.

P.E. Offman [10] even noticed a regular pattern of location of trap dikes in the axial part of asymmetric synclines in the Tungusska depression. These synclines, he believes, were formed as a result of subsidence of surrounding rocks along with the dikes. He bases his belief on the fact that there is no crushing or uplifting of beds near contacts. He writes: "This subsidence (including the enclosed dikes) probably occurred because of a volume decrease resulting from the cooling off of the dikes. Solidification of the molten magma in the fracture and at great depth was probably not simultaneous, and consequently the upper part of the dike, along with the enclosing rocks, had to drop." We believe that subsidence of the blocks surrounding vertical trap bodies could occur in certain cases, but one should not speak of regular development of this kind of structure, of selective localization of trap dikes in axial parts of synclines, and even call such structures by a special term (asymmetric synclines), for the majority of trap occurrences (near the Viluy, Angara, Naman, and other rivers) usually show opposite relations, namely, the uplift of surrounding rocks near intrusive contacts.

The mechanism of trap intrusions also depends greatly on the mass of the moving magma (manifested in the thickness of intrusive bodies) that depends principally on the intensity of the subsurface stress at the time of intrusion, the depth of the magma chamber, the activity and mobility of the magma, its chemical composition, the competence of the sedimentary blanket (generally and of specific rock units), the structures present, etc.

The traces of a tectonic stress that existed at the time of a wedge-like magmatic intrusion are present in the form of numerous microfractures in the mineral grains (plagioclase, olivine, pyroxene) crystallized during early stages of intrusion; the same minerals of later stages of crystallization do not exhibit any traces of stress. This fact points to the disappearance of the tectonic stress before the completion of solidification of the intrusives. The dikes that passively filled in existing fractures do not exhibit fracturing in the constituent minerals.

The formation of trap intrusions depends greatly on the presence of "open" fractures that could serve as channels of magmatic flow from the depths into upper levels of the earth's crust. Ascending magma was apparently controlled, as pointed out by K.O. Kratz and A.A. Polkanov, by the values of the magmatic pressure and the hydrostatic pressure of the overlying beds. Magma ascends if the hydrostatic pressure overcomes the weight of the overlying beds and the magmatic injections are extended laterally, forming sills. The bedding and interformational planes contribute to the lateral extension of magma. The available data on the depth of trap sills and on their thickness permit us to agree with K.O. Kratz, who considers the great thickness of nearly horizontal intrusives to be the result of thinner overlying beds or their lower pressure upon magma [13].

Table 2 shows that in the Berezov basin, composed of thick Lower Cambrian sedimentary rocks, trap sills not exceeding 85 meters in thickness occur at a depth of 500 to 2,000 meters, but within the Tungusska depression, the thickest intrusive bodies (200 meters and more) are confined to relatively higher Paleozoic systems such as the Ordovician, Silurian, or even more commonly, the Permian productive strata of the Tungusska complex. The thickness of sills rarely exceeds 150 meters, and trap rocks do not occur as tuffs (usually without bedding or crudely bedded) overlying the productive beds.

According to data on the depths of trap bodies and the thickness of the sedimentary blanket, we may approximate weight of the overlying rocks that the ascending magma had to overcome. In the Berezov basin, where the sedimentary blanket is from 3,000 to 5,000 meters thick, the ascending magma had to overcome a hydrostatic pressure of 1,000 atmospheres (at the rate of about 280 atmospheres per kilometer of depth). In some parts of the Tungusska depression, where the sedimentary blanket is considerably thinner, the ascending magma could have had much less pressure in order to overcome the weight of the overlying beds; it was probably no more than 400 to 500 atmospheres.

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ALTERATION OF WALL ROCK SPILITE AT THE BURIBAY CHALCOPYRITE DEPOSIT IN THE SOUTHERN URALS

by

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The chalcopyrite bodies in the Buribay deposit occur in keratophyre spilite rocks near the top of the Baymak-Buribay layers (S_2), overlain disconformably by volcanic-sedimentary rocks supposedly of Ulutau age (D_2).

The spilite and its tiff constitute the wall rocks; extrusive albitophyres are exposed 3 kilometers east of the deposit in the form of a blanket and are interbedded with spilite and siliceous shale or jasper.

The spilites proper (with spilitic and intersertal structures), amygdaloids (with vuggy textures), variolites, and porphyries are distinguishable macroscopically. These massive and in places slightly schistose, grey-green rocks commonly have spheroidal jointing; the spheroids are 10 centimeters to 2 meters in diameter; the spaces between them are filled in by phyllite of the same composition.

Microscopic study disclosed that the spilite consists of albite-oligoclase, chlorite, and quartz; relict pyroxene (augite) is rare; more basic plagioclase than albite-oligoclase was not found; sericite, sphene, and locally such ore minerals as pyrite and chalcopyrite occur in small amounts; calcite and epidote were found in a few places.

Intersertal and variolitic structures are most abundant in the spilite; the rocks are commonly vuggy. Albite-oligoclase, chloritic mesostasis, and secondary quartz constitute the matrix.

Albite-oligoclase also occurs as rare phenocrysts. Plagioclase grains are frequently enveloped by albite that occurs around chlorite or quartz aggregates where the albite replaces the central part of plagioclase grains. Chlorite consists of two varieties, pennine and prochlorite, distributed at random. Some of the secondary quartz is cataclastic and has wavy extinction. Chlorite and rarely-occurring sericite commonly do not show parallel orientation; only in altered rocks near ore bodies are these mineral grains slightly oriented parallel to the contact of the ore bodies. Vugs are filled in here by chlorite and quartz.

Thus, on the basis of petrographic features, the spilites of this region are altered rocks consisting of secondary minerals only.

In order to determine the alteration stage minerals, we compared the spilites of the Buribay deposit with altered greenstone near other sulfide deposits in the Urals, for example, with spilite of Blyava [2] and quartz-chlorite schist of Kalata and Degtyarka [1], i.e., with nearly unaltered and intensively-altered rocks. The comparison was based on the mineral composition (Table 1) and the chemical assays of the rocks (Table 2).

Three samples of fresh and well-preserved spilites were taken in the area of the Buribay deposit for chemical assays.

Sample 631 is a core from the 112-meter depth of Hole 117, drilled 300 meters east of the ore body. This is a massive, hard, greenish-grey rock with calcite veinlets and disseminated pyrite. Two samples were taken from the currently mined open pit:

1. Sample 1085: from the eastern wall of the 285-meter level, 40 meters from the ore body, well-packed, fine-grained, greenish-grey rock with small vugs filled by chlorite but in places containing disseminated sulfides;

2. Sample 573: 295 meter-level, 20 meters west of the ore body, chloritized, greenish-grey spilite with disseminated pyrite.

The mineral composition of spilite from the Buribay deposit was computed on the basis of the chemical assays and the qualitative microscopic data and was checked by the grain-counting method using an integration table; the composition of spilite from the Blyava deposit was computed on the basis of chemical assays and petrographic descriptions presented by V.A. Zavaritskiy [2]. The chemical assays and mineral composition of the quartz-chlorite and chlorite schist from

Table 1

Mineral Composition of Diabasic Greenstone Wall Rocks in the Urals
(weight percentages)

	Minerals	Spilite of microlitic spherolitic lava, hanging wall, Blyava deposit	Spilite Sample 631, drill hole 117, 300 meters from Buribay deposit	Spilite Sample 1085, open pit, Buribay deposit	Spilite Sample 573, open pit, Buribay deposit	Quartz chlorite schist Degtyarka deposit	Chlorite schist, Kalata deposit
1	Albite or albite-oligoclase	49.65	26.21	30.60	5.36	14.25	3.65
2	Pyroxene (pigeonite)	12.27	--	--	--	--	--
3	Chlorite (pennine and prochlorite)	13.95	33.97	35.10	52.00	60.66	86.60
4	Quartz	7.97	27.52	30.80	--	--	--
5	Actinolite	2.56	--	--	--	--	--
6	Sericite	1.81	1.53	0.79	1.61	1.60	1.91
7	Epidote	--	--	--	--	4.56	--
8	Calcite	5.79	3.17	--	--	--	--
9	Sphene	--	0.09	--	0.09	1.95	1.71
10	Ilmenite	--	--	1.21	--	--	--
11	Titanomagnetite	6.00	--	--	--	--	--
12	Magnetite	--	--	--	--	--	5.78
13	Pyrite	--	7.51	1.59	2.05	0.46	--
14	Chalcopyrite	--	--	--	--	--	0.43
15	Kaolinite	--	--	--	4.49	--	0.43
	Total	100.00	100.00	100.00	100.00	100.00	100.00

Degtyarka and Kalata are by L.M. Afanasiyev [1].

A comparison of the mineral composition of the rocks as compiled in Table 1 reveals that acidic plagioclase and primary melanocratic minerals occur in great amounts only in slightly altered spilites of Blyava, in which the content of secondary quartz, chlorite, and other minerals is low. The more intensively the greenstone wall rocks are altered, the greater are the amounts of chlorite and the smaller the amounts of plagioclase and primary melanocratic minerals they contain. The comparison demonstrates that the mineral composition of spilites of the Buribay deposit is transitional between that of spilites from Blyava and chlorite schist of the central Urals. Besides the spilites of the Buribay deposit, and greenstone of Buribay, Blyava, Kalata, and Degtyarka, we used the assays of spilitic diabase porphyries from the chalcopyrite deposit of Kaban (data by V.P. Loginov) and the average composition of spilites after Sundius [4] for comparative purposes. Thus, for comparison, we selected rocks altered to varying degrees and sampled beyond the narrow zone of metasomatic alteration near ore bodies. In order to make the comparison easier, we used only one assay of spilite from the Buribay deposit (Sample 631) representing a medium rate of alteration and taken farther (300 meters) from the ore body than the other samples.

The figures of chemical assays were recalculated as percentages of standard cells by the T.F. Barth method [5], who compares the composition of rocks with equal volumes (Table 2). The recalculation figures that express the composition of standard cells are illustrated in Figure 1, where Na_2O, CaO, MgO, Al_2O_3, SiO_2, and H_2O are shown according to the respective number of cations within standard cells. Since chloritization, requiring a magnesium supply, is the most typical hydrothermal alteration of greenstone spilite, rocks of extremely different magnesium content represent the external vertical lines of the diagram. Thus, the average

Table 2

Chemical Composition of the Diabasic Greenstone Wall Rocks in Percent of Standard Cells, Computed by the T. F. Barth method (1952)

	Average chemical composition of spilites according to Sundius [5]		Microlitic spilites of spherolitic lava from hanging walls of Blyava deposit [2]		Diabase porphyry, Kaban deposit, Sample 1069[1]		Spilite Sample 631, Buribay deposit		Quartz-chlorite schist, Degtharka deposit [1]		Chlorite schist, Kalata deposit [1]		Spilite Sample 1085, Buribay deposit		Spilite Sample 573, Buribay deposit	
	I		II		III		IV		V		VI		VII		VIII	
	a*	b**	a*	b**	a*	b**	a*	b**	a*	b**	a*	b**	a*	b**	a*	b**
SiO_2	51,22	47,85	52,46	47,97	48,93	44,42	54,92	48,90	45,65	40,66	26,86	26,37	58,48	51,72	50,04	45,48
TiO_2	3,32	2,3	0,94	0,66	0,83	0,54	0,05	0,05	0,79	0,53	0,70	0,53	0,64	0,42	0,05	0,05
Al_2O_3	13,66	14,98	15,33	16,47	18,19	19,40	15,07	15,78	15,09	16,47	19,30	22,30	15,07	15,66	17,44	18,72
Fe_2O_3	2,84	1,96	4,09	2,85	4,44	3,05	0,16	0,10	2,04	1,33	4,04	3,0	2,10	1,38	4,90	3,27
FeO	9,20	7,35	6,13	4,83	8,01	6,05	9,23	6,90	12,87	9,68	28,77	23,72	6,86	5,25	8,16	6,22
MnO	0,25		0,18				0,08		0,14		0,14		0,27		0,09	
CaO	6,89	6,90	5,98	5,87	3,06	3,0	2,06	1,98	1,81	1,71	0,47	0,47	0,07	0,10	Сл.	—
MgO	4,55	6,34	4,69	6,42	5,40	7,30	7,44	9,84	11,51	15,24	12,41	18,17	6,32	8,33	9,36	12,66
Na_2O	4,93	8,92	5,62	9,88	4,60	8,06	2,98	5,13	1,70	2,88	0,45	0,83	3,55	6,05	0,61	1,09
K_2O	0,75	0,89	0,19	0,22	0,92	1,09	0,16	0,16	0,20	0,21	0,34	0,41	0,08	0,10	0,17	0,16
H_2O^+	1,88	(11,78)	3,81	(23,22)	3,86	(23,38)	5,65	(33,54)	7,53	(44,67)	7,67	(50,21)	4,57	(26,92)	5,41	(32,81)
P_2O_5	0,29	0,22			1,46	1,14			0,08	0,05						
CO_2	0,94	(1,18)														
S							3,62	(6,04)	0,24	(0,37)	0,22	(0,41)			1,00	(1,69)
H_2O^-					0,08		0,16						0,23			
SO_3					0,41	(0,27)							1,87	(1,17)	2,22	
Total	100,72	97,71	100,23	95,17	100,20	(117,70)	99,77	88,84		88,81	100,81	95,74	100,07	89,01	99,48	87,65

Note: Comma represents decimal point.

[1]Samples of V. P. Loginov assayed in the Chemical Laboratory of the Institute of Geology, Petrography, Mineralogy, and Geochemistry of Ore Deposits at the Academy of Sciences of the U. S. S. R., by P. N. Nisenbaum, Analytical Chemist.

*a = weight percentages (of oxides)

**b = number of cations in a standard oxide cell

Appendix to Table 2

Composition of Rocks Within Standard Cells

I	$K_{0,9}$	$Na_{8,9}$	$Ca_{6,9}$	$Mg_{6,3}$	$Fe_{9,3}$	Al_{15}	$Ti_{2,3}$	$Si_{47,8}$	$P_{0,2}$	$[O_{148,2}$	$(OH)_{11,8}]_{160}$
II	$K_{0,2}$	$Na_{9,9}$	$Ca_{5,9}$	$Mg_{6,4}$	$Fe_{7,7}$	$Al_{16,5}$	$Ti_{0,6}$	Si_{48}		$[O_{136,8}$	$(OH)_{23,2}]_{166}$
III	$K_{1,1}$	$Na_{8,1}$	$Ca_{3,0}$	$Mg_{7,3}$	$Fe_{9,1}$	$Al_{19,4}$	$Ti_{0,5}$	$Si_{44,4}$	$P_{1,1}$	$[O_{136,6}$	$(OH)_{23,4}]_{160}$
IV	$K_{0,2}$	$Na_{5,1}$	$Ca_{1,9}$	$Mg_{9,8}$	$Fe_{7,0}$	$Al_{15,7}$	$Ti_{0,05}$	$Si_{48,9}$		$[O_{126,5}$	$(OH)_{33,5}]_{160}$
V	$K_{0,2}$	$Na_{2,8}$	$Ca_{1,7}$	$Mg_{15,2}$	Fe_{11}	$Al_{16,4}$	$Ti_{0,5}$	$Si_{40,6}$	$P_{0,05}$	$[O_{115,3}$	$(OH)_{44,7}]_{160}$
VI	$K_{0,4}$	$Na_{0,8}$	$Ca_{0,4}$	$Mg_{18,1}$	$Fe_{25,7}$	$Al_{22,3}$	$Ti_{0,5}$	$Si_{26,4}$		$[O_{109,8}$	$(OH)_{50,2}]_{160}$
VII	$K_{0,1}$	Na_{6}	$Ca_{0,1}$	$Mg_{8,3}$	$Fe_{6,6}$	$Al_{15,6}$	$Ti_{0,4}$	$Si_{51,7}$		$[O_{133,1}$	$(OH)_{26,9}]_{160}$
VIII	$K_{0,2}$	$Na_{1,1}$	—	$Mg_{12,6}$	$Fe_{9,4}$	$Al_{18,7}$	$Ti_{0,05}$	$Si_{45,5}$		$[O_{127,2}$	$(OH)_{32,8}]_{160}$

Note: Comma represents decimal point.

composition of spilites according to Sundius and the Kalata chlorite schist were plotted along these external lines. The points representing the magnesium cation content in the two external verticals were bound by a straight line. All other samples were located in such a way that the magnesium cations contained in their standard cells were plotted along this straight line. Vertical lines were drawn through the points corresponding to magnesium content in standard cells of other samples. The values of other cations of the respective standard cells were plotted along these vertical lines. Then the points representing identical cations were connected.

Figure 1 illustrates that spilites of the Buribay deposit are transitional between the nearly unaltered spilite of Blyava or the

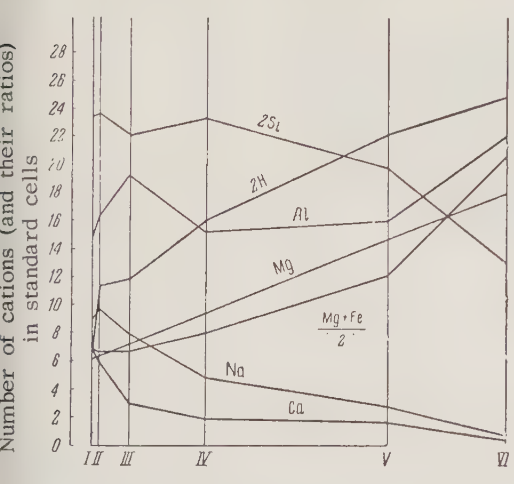

Fig. 1. Diagram Comparing the Chemical Composition of Spilites and Chlorite Schists, Altered to Varying Degree

I -- Average composition of spilites according to Sundius; II -- Blyava microlitic spilite; III -- Diabase porphyry from the Kaban deposit, Sample 1069; IV -- Buribay spilite, Sample 631, Drill Hole 117; V -- Quartz-chlorite schist, Degtyarka deposit; VI -- Kalata chlorite schist.

average spilite composition according to Sundius and the intensively-altered Degtyarka and Kalata greenstone that turned into chlorite schist. Thereby, the Buribay spilites are closer to unaltered spilite. The spilitic porphyries of the Kaban sulfide deposit are between the Blyava and Buribay spilites, and this indicates a less intense alteration than the Buribay spilites.

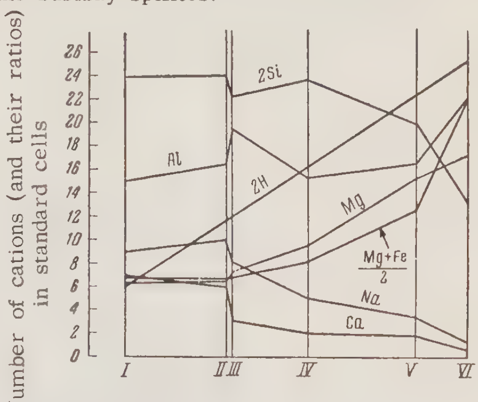

Fig. 2. Diagram Comparing the Chemical Composition of Spilite and Chlorite Schist Altered to Varying Degrees

Despite weak schistosity, the chlorite schist is altered more intensively.

Figure 2 illustrates the degree of hydration of rocks and therefore depends on the amount of water-bearing minerals present. The diagram is based on the same principle as the previous one, but the horizontal distances between the samples are different. Of course, the degree of hydration is the principal indication of hydrothermal alteration of rocks, but because of the inaccuracy of water determinations by any analytical method, the conclusions based on the water content cannot be very accurate. In Figure 2, the horizontal distances are changed and the samples from the Blyava and Kaban deposits approach each other, while the rocks of the Buribay deposit approached the quartz-chlorite and chlorite schist of Degtyarka and Kalata, i.e., they approached intensively-altered greenstone.

Both diagrams show the change in chemical composition of rocks from fresh spilite to chlorite schist; the sodium and calcium content is continuously diminished and magnesium, water, and iron percentages rise. The alumina content does not follow any regular changes, but that of silica clearly drops.

Thus, the replacement of plagioclase by chlorite in spilite of the Buribay deposit was a process during which alkalines and calcium were extracted and certain amounts of magnesium were brought in. Although the silica content clearly drops, the amount of secondary quartz increases, most likely at the expense of decomposed acidic plagioclase.

The composition of the three analyzed spilite samples of the Buribay deposit were plotted on a triangular diagram (Figure 3), where the quartz-chlorite and chlorite rocks of Degtyarka and Kalata were also placed for comparative purposes (using L.M. Afanas'yev's data [2]). The triangular diagram illustrates the dependence of the mineral composition on the ratio of chemical components that determine the mineral composition of rocks [3]. The corners of the triangle represent 100 percent Si, Al, and Fe + Mg, respectively. These elements were selected because chlorite, quartz, and albite are always principal minerals of spilite and of the products of its alteration. Na and Ca are mobile components. The plotted points illustrate that spilites turning into chlorite schist lose silica and become rich in Mg + Fe; thus, their essential chemical compositions change.

In comparing the mineral and chemical composition and paragenesis of Buribay spilites and of strongly altered rocks (chlorite schist), one may conclude that the spilites of the Buribay deposit are considerably altered.

Even without mentioning that the composition of altered Buribay spilites differ greatly from slightly altered Blyava spilites, it is clear that the metamorphic alteration of the Buribay spilites was even more intense than that of the wall rocks of the Kaban deposit in the central Urals.

The metamorphic and metasomatic alterations of spilite in the area of Buribay chalcopyrite deposits extends for hundreds of meters or even for kilometers from the ore bodies. At the same time, the specific alteration directly confined to ore bodies, forms zones whose thickness rarely exceeds 10 meters. The near ore alterations are expressed in the form of silicification and chloritization of wall rocks (Fig. 4) that turn into quartz-chlorite schist and quartzite impregnated by sulfides. The original structure of the wall rock can no longer be recognized.

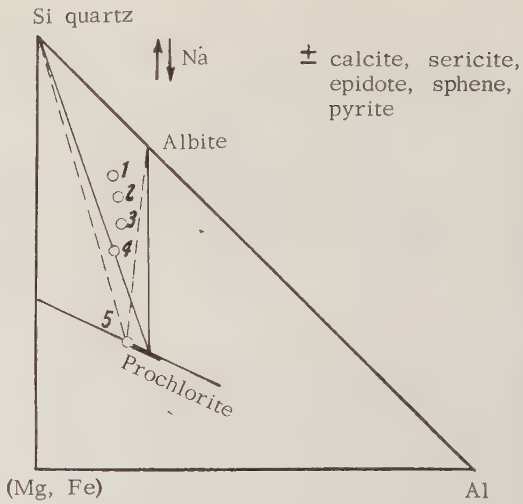

Fig. 3. Diagram that Compares the Composition and Paragenesis of Spilite and Chlorite Schist

1 -- Sample 1085, spilite from an open pit 40 meters east of the Buribay ore body; 2 -- Sample 631, spilite from Drill Hole 117, 300 meters east of the Buribay ore body; 3 -- Sample 573, spilite of an open pit, 30 meters west of the Buribay ore body; 4 -- Quartz-chlorite rock, Degtyarka deposit; 5 -- Chlorite rock, Kalata deposit.

In a number of cases, zonal distribution of metasomatic minerals appear in the following sequence: 1) pyrite, small amounts of quartz and chalcopyrite; 2) quartz, pyrite; 3) chlorite, quartz, pyrite; 4) chlorite, quartz, albite, small amounts of pyrite.

All the four zones are present in Sample 26k, which includes both ore and altered spilite (Fig. 5). The boundaries of the zones are clear, especially between the first and second zone. In the second zone, textural relicts of the replaced spilite can be recognized because of vugs filled in by quartz. The fourth zone, the widest, consists of spilite with disseminated pyrite and essential amounts of secondary quartz. All the zones are the result of hydrothermal alteration of spilite during which iron and sulfur were brought in. The thickness of the zones ranges from centimeters to a few meters. The zones of near ore alteration are present everywhere within the deposit, but the intensity of their development varies from place to place.

The mineral composition of partially altered spilites is in principle the same as those occurring farther from ore bodies; only the quantitative ratios change, sometimes considerably. Both the partially altered and remote rocks reveal the same kind of changes in the mineral and chemical composition; only the intensity of the alteration

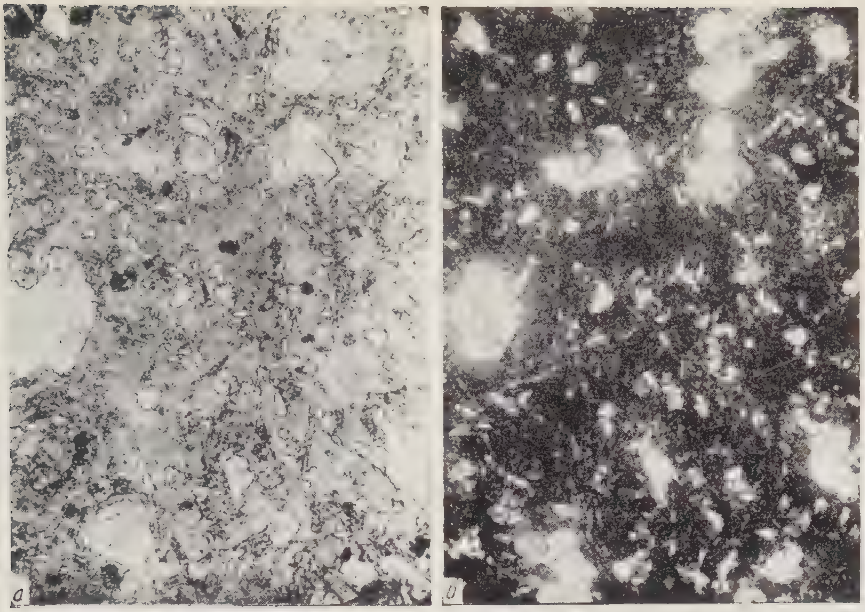

Fig. 4. Quartz-chlorite Wall Rock with a Spilitic Relict Structure. Thin section 21 magnified 46X; a) without analyzer; b) with analyzer

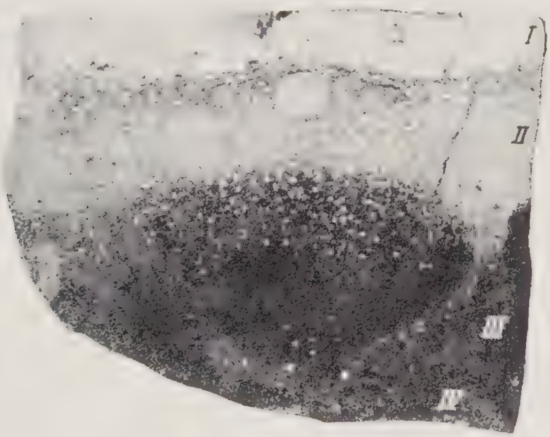

Fig. 5. Contact of Chalcopyrite Ore with Spilite. Four metasomatic zones can be seen:

I -- Pyrite; II -- Quartz; III -- Chlorite, quartz, pyrite; IV -- Chlorite, albite, quartz, small amounts of pyrite.
Sample 26. Natural size. Polished section.

near an ore body is greater. For comparative purposes, the chemical assay of an altered spilite (Sample 573) and that of a slightly altered spilite (Sample 1085), taken at different distances from ore bodies, were recalculated according to the Barth method to get the following characteristic figures:

Sample 1085:

$$K_{0.1}Na_{6.0}Ca_{0.1}Mg_{8.3}Fe_{6.6}Al_{15.6}Ti_{0.4}Si_{51.7}[O_{133.1}(OH)_{26.9}]_{160}.$$

Sample 573:

$$K_{0.2}Na_{1.1}Mg_{12.6}Fe_{9.4}Al_{18.7}Si_{45.5}[O_{127.2}(OH)_{32.8}]_{160}.$$

The figures indicate the supply and extraction of components in the course of hydrothermal alterations, which, in the case of particular cations, can be expressed in the following form:

Supply	Extraction
K = 0.1	Na = 4.9
Mg = 4.3	Ca = 0.1
Fe = 2.8	Si = 6.2
Al = 3.4	

Similarly altered wall rocks also occur at other sulfide deposits in the Urals, as indicated by L.M. Afanes'yev's publication [1].

Thus, the hydrothermal alteration of spilite in the Buribay deposit is, on the basis of chemistry, similar to the extensive rock alterations produced by newly introduced magnesium and iron and extraction of calcium and sodium.

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THE PALEOZOIC STRUCTURAL AND FACIES SUBZONES IN THE TURKESTAN-ALAY MOUNTAIN SYSTEM (SOUTHERN TIEN SHAN)

by

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The Turkestan-Alay mountain system, which is a part of the Paleozoic geosynclinal zone of the Southern Tien-Shan, can be divided into structural and facies subzones. The subzones are divided into two groups with reference to their geologic composition and development; their respective synclinal developments differ sharply. The author attempts to distinguish a general pattern in the geosynclinal development of the Southern Tien-Shan during the Paleozoic.

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The principal features of the structural and facies zones in the Turkestan-Alay mountain system were first recognized by A. V. Peyve [4] and V. I. Popov [5], defined by N. M. Sinitsyn (1942) and developed still further by D. P. Rezvoy (1953).

The last two authors divide the mountain system into districts on the basis of the principal Hercynian structures, i. e., large late Paleozoic structural basins separated by extensive elevations; but they leave the earlier geologic development of the subzones without adequate consideration even for the middle Paleozoicum. Therefore, it is not clear how the structures and sedimentary features of the late Paleozoic basins developed during the middle and lower Paleozoic. At the same time, the Paleozoic history of the Tien-Shan is a single evolutionary process during which the structures and facies within the geosyncline developed alternately. Therefore, the specific features of geology of the upper units and the chronologic development of the geologic composition of the Tien-Shan as a whole can hardly be understood without knowledge of the composition and development of the lower structural and facies unit.

Besides, D. P. Rezvoy considers the upper Paleozoic elevations to be Hercynian anticlinoria and the upper Paleozoic basins to be Hercynian synclinoria, but this view is not confirmed by fact.

* * *

The Turkestan-Alay mountain system is a constituent of the Southern-Tien Shan, which was a geosyncline during the entire Paleozoic. The northern boundary of the southern Tien-Shan lies within the Naryn Basin and the Chatkal district, an independent intermediate zone of the Tien-Shan. This intermediate zone, like the northern Tien-Shan, differs basically from the southern Tien-Shan with regard to geologic composition and history. All the three large regions are independent structural and facies zones of the Paleozoic geosynclinal system of the Tien-Shan, as defined by V. I. Popov [5]. The Southern Tien-Shan, like the other zones, is not a geologically homogeneous unit; it consists of subzones whose geologic history and composition essentially differ. This can be seen, for example, in the composition of the southwestern part of Southern Tien-Shan, i. e., the Turkestan-Alay mountain system. Within this region, several subzones can be distinguished that divide the Turkestan-Alay mountain system into broad parallel belts trending throughout the entire region.

There are two types of subzones. Each type includes subzones having similar geologic composition and history, while subzones of different types differ greatly in this respect. The subzones of the first and second types alternate laterally (Figure 1). The subzones represent geosynclines and geanticlines of the second order in the general structure of the Paleozoic Southern Tien-Shan geosyncline.

The above terms are used in this paper as follows: As defined by A. D. Arkhangel'skiy and N. S. Shatskiy [6], the entire area subject to a geosynclinal process that taking place during one or another period

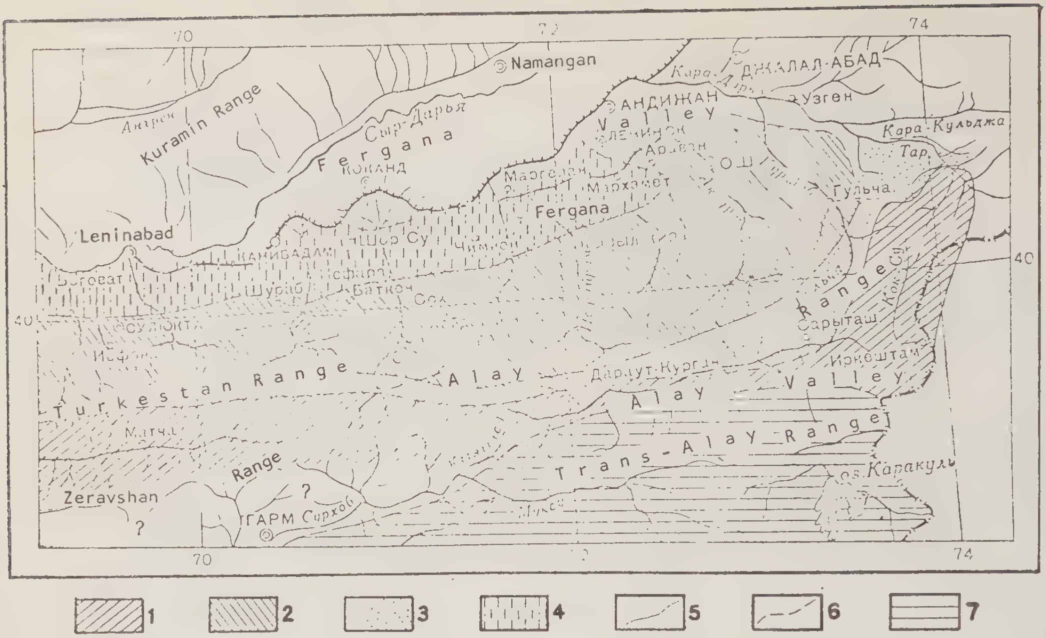

Fig. 1. Structural and facies subzones of the Turkestan-Alay mountain system

Subzones of the first type -- lower (?) and upper Paleozoic structural basins (geosynclines of the second order) and upper Paleozoic elevations (geanticlines of the second order): 1 -- Zeravshan-Eastern Alay; 2 -- High front ranges.

Subzones of the second type -- lower (?) and upper Paleozoic elevations (geosynclines of the second order) and upper Paleozoic structural basins (geosynclines of the second order: 3 -- Gulcha; 4 -- Kara-Chatyr.

Boundaries of zones and subzones: 5 -- established; 6 -- assumed; 7 -- zone of external bend of the Pamir.

is called here a geosynclinal region. This region is further divided into geosynclinal systems, which are in turn divided into geosynclines and geanticlines. Geosynclines are zones of intense subsidence, and elevations dominate geanticlines.

In the Southern Tien Shan, a geosyncline in the Tien Shan system, we can see that a geosyncline is a sharply differentiated structure, within which can be distinguished larger substructures called geosynclines and geanticlines of the second order.[1]

Unlike geosynclines and geanticlines, the geosynclines and geanticlines of the second order have: 1) smaller extension, because they occur within a geosyncline and are a part of it; 2) a shorter duration, because they become transformed, one into another, during the period of existence of a geosyncline which they constitute.

However, there are geosynclines and geanticlines of the second order within the Paleozoic Tien Shan geosyncline, which existed during the entire geosynclinal cycle

[1]The term "geanticline of the second order" has been used by V. A. Nikolayev [3], who applied the term to local elevations formed during a geosynclinal cycle in central parts of geosynclinal basins.

We do not use the terms "intrageosyncline" and "intrageanticline," suggested by V. V. Belousov [2], for two reasons:

1. V. V. Belousov applies the term "geosyncline" to a geosynclinal region, according to our definition, and his "intrageosyncline and intrageanticline" correspond to our geosyncline and geanticline. Our geosyncline and geanticlines of the second order are structures of a higher order than intrageosynclines and intrageanticlines of Belousov.

2. The Paleozoic history of the Southern Tien Shan geosyncline and the second order geosynclines and geanticlines constituting it do not indicate the mechanism of general and partial inversion to which V. V. Belousov points.

without being inverted. The Fergana range, between the basins of the Tar and Urumbash Rivers, is an example of a geosyncline of the second order that was probably not inverted during the entire Paleozoic. The Suluterek massif, an exposure of the Precambrian basement, is an example of a geanticline of the second order that existed during the entire Paleozoic. This Precambrian massif is located on the southern slope of the Tien Shan, within northwestern Kashgaria. However, these two regions are beyond the scope of this article.

Let us now review the subzones of the Turkestan-Alay mountain system.

Subzones of the First Type. This group includes the lower (?) - middle Paleozoic structural basins, such as those of Zeravshan-Eastern Alay, and the Vysokiy[1] (geosynclines of the second order) and Upper Paleozoic elevations (geanticlines of the second order).

A rapid subsidence of the subzones of the first type led to the accumulation of thick extrusive-sedimentary strata of marine facies during the Lower (?) - Middle Paleozoic.[2]

The Middle Paleozoic unit in the Zeravshan-Eastern Alay subzones is 15 to 16 kilometers thick. The thickness and composition of the formations do not change essentially within the area.

The average thickness of the Middle Paleozoic unit in the subzone of the Vysokiy front range is considerably less -- 8 to 9 kilometers. Besides, the margins of the front range exhibit sharp changes in thickness and completeness of sections even within short intervals. These changes are impelled by tectonic differentiation of the subzone, its disintegration into local narrow zones and areas whose depth and time of subsidence differ considerably.

The lower (?) - middle Paleozoic sedimentation in the subzones of the first type continued without tectonic interference. There were only epirogenic movements that led to local erosion and stratigraphic interruptions. Among them the Pre-Shivet (or Shivet) interruption was regional and caused deep erosion in both subzones of the first type. The pre-Late Devonian and pre-Visean interruptions were noticeable only within the subzones of the Vysokiy front range. The former expands only locally and in quite different forms, but the latter expands everywhere but not uniformly. The depth of erosion varies widely within the area of the subzones. That is to say, the tectonic differentiation in the subzone of the Vysokiy front range determines the change in the thickness and composition of the middle Paleozoic sections over short distances.

Magmatic activity in the lower (?) - middle Paleozoic within the subzone of the first type produced basic and intermediate extrusives; intrusives of this age are not known.

The Caledonian-Early Hercynian (pre-Middle Carboniferous) structures in both subzones of the first type are generally synclines or broad and deep structural basins separating the lower-middle Paleozoic elevated subzones of the second type.

Early in the Middle Carboniferous, the character of the oscillations changed sharply within the subzones of the first type; the lower (?) - middle Paleozoic structural basins were inverted into elevations. The elevations were subject to erosion and no Upper Paleozoic sediments were deposited in the greater part of the subzones of the first type.

In places, however, local basins emerged in the subzones of the first type, in which were accumulated Upper Paleozoic flysch or molasse sediments. The latter's thickness and sequence are not uniform even within local basins.

In the local basins of the Zeravshan-Eastern Alay subzone, for example, the entire Upper Paleozoic section commonly consists of Upper Carboniferous conglomerate up to 800 meters thick, containing a triticit fossil fauna and disconformably overlying various layers of middle Paleozoic sediments. The Upper Carboniferous conglomerate is locally overlain by conglomerate and shale beds of the Shvagerinian formation. Thus, Middle Carboniferous, the top of Upper Carboniferous, and Upper Permian sediments were deposited everywhere, or almost everywhere, even in the local structural basins of the Zervashan-Eastern Alay subzone, but the other parts of the subzone do not have known Upper Paleozoic sediments at all.

The Upper Paleozoic sediments are thicker and more extensive within the subzone of the Vysokiy front range but still poor in varieties and relatively thin.

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[1]The boundaries of the subzones are shown in Figure 1.

[2]A brief list of data on the composition and structure of the Paleozoic section in the subzones in the Turkestan-Alay mountain system is compiled in the table attached and therefore not repeated in the text.

The Lower Carboniferous conglomerate (Triticites unit, 500 to 2,000 meters thick) in the subzone of the Vysokiy front range are commonly underlain by a flysch-like sandstone, shale, and conglomerate group 400 to 3,000 meters thick of the upper half of the Middle Carboniferous. The lower units of the Lower Carboniferous, composed of carbonates 100 to 1,000 meters thick, are known only locally (the upper Isfayram River and the basin of the Chauvay River). The Triticit unit is in a few places (the upper Ak-Bura River) disconformably overlain by thin carbonate and shale sediments of the Schwagerina unit. Thus, in the local structural basin of the subzone of the Vysokiy front range, the lower part of the C_2 strata are absent, while upper C_3 and almost the entire Permian (except for the Schwagerina unit) seem to be absent everywhere. Within the remaining area of the subzone of the Vysokiy front range, as in the subzone of Zeravshan-Eastern Alay, upper Paleozoic sediments are absent entirely. It seems to us that in these areas sediments of the late Paleozoic were never deposited.

The inversion of the lower and middle Paleozoic structural basins into upper Paleozoic elevations was not accompanied by folding within both subzones of the first type, although deep erosion can be noticed nearly everywhere; upper Paleozoic sediments overlie various units of the Middle Carboniferous with stratigraphic interruption but without angular unconformity.

The Middle Carboniferous sedimentation, if present, was not disturbed by tectonic processes. Only the pre-Late Carboniferous tectonison was significant and caused deep erosion prior to the sedimentation of Upper Carboniferous conglomerate that in places overlies the lower unit with angular unconformity.

Finally, the geosynclinal development of the subzones of the first type ended with folding that apparently took place in the Early Permian. Consequently, the Paleozoic folds within the subzones of the first type were formed principally by Early Permian tectonism, but the structures were also recognizably affected by the pre-Late Carboniferous tectonism.

The late Paleozoic magmatic activity within the subzones of the first type was fully dependent on tectonism; small intrusions of basic and ultrabasic composition were dated as Early Carboniferous to Middle Carboniferous; they apparently are synchronous with the pre-Middle Carboniferous tectonison; the small intrusions of acidic magma perhaps took place during the pre-Late Carboniferous tectonism and finally the intensive Early Permian (?) folding caused the intrusion of large masses of acidic magma.

The Hercynian fold structures within both subzones of the first type definitely are of synclinal type.

The Hercynian structures within the subzones of Zeravshan-Eastern Alay form a tremendous and complicated "trough-shaped" synclinorium, screened at the north end of the Eastern Alay, at the boundary of the Fergana structure. The synclinorium is separated from the latter structure by a deep fault trending along the Tar River (Figure 2).

The subzone of the Vysokiy front range is generally also a synclinorium consisting of three parallel belts trending along the entire length of the synclinorium. The central belt is structurally a syncline. The stratigraphy of the middle Paleozoic sediments within this belt is most complete and consists of shale, interbedded carbonates and shale, and extrusives, which are the principal units, although local but thick upper Paleozoic sediments are present here, too. The southern and northern belts are marginal anticlines, and their middle Paleozoic sections are thinner and consist largely of carbonate rocks and coarse clastic layers of middle Paleozoic age. Upper Paleozoic sediments do not occur here. Thus, the Hercynian structure as a whole, within the subzone of the Vysokiy front range, can be clearly recognized as a syncline (Figure 3).

Thus the early to middle Paleozoic structural basin turned into an late Paleozoic elevation, but no folding took place in the subzones of the first type at this time, and consequently both the Caledonian and Hercynian structures retained a synclinal character.

Subzones of the Second Type (of Gulcha and Kara-Chatyr) are structural units opposite to those of the first type; they are early to middle Paleozoic elevations (geanticlines of the second order) that turned into late Paleozoic structural basins (geosynclines of the second order). In the early or middle Paleozoic elevations of the subzones of the second type relatively thin Middle Paleozoic sediments consisting largely of coarse clastic matter were accumulated. The maximum thickness of the middle Paleozoic section in the subzone of Gulcha hardly reached 3 to 3 1/2 kilometers; within the greater area of the subzone it ranges from 1,000 to 1,500 meters and in places perhaps even less. In the latter case, the upper Paleozoic sediments directly overlie Silurian beds. The average thickness of the Middle Paleozoic sediments in the Gulcha subzone is almost

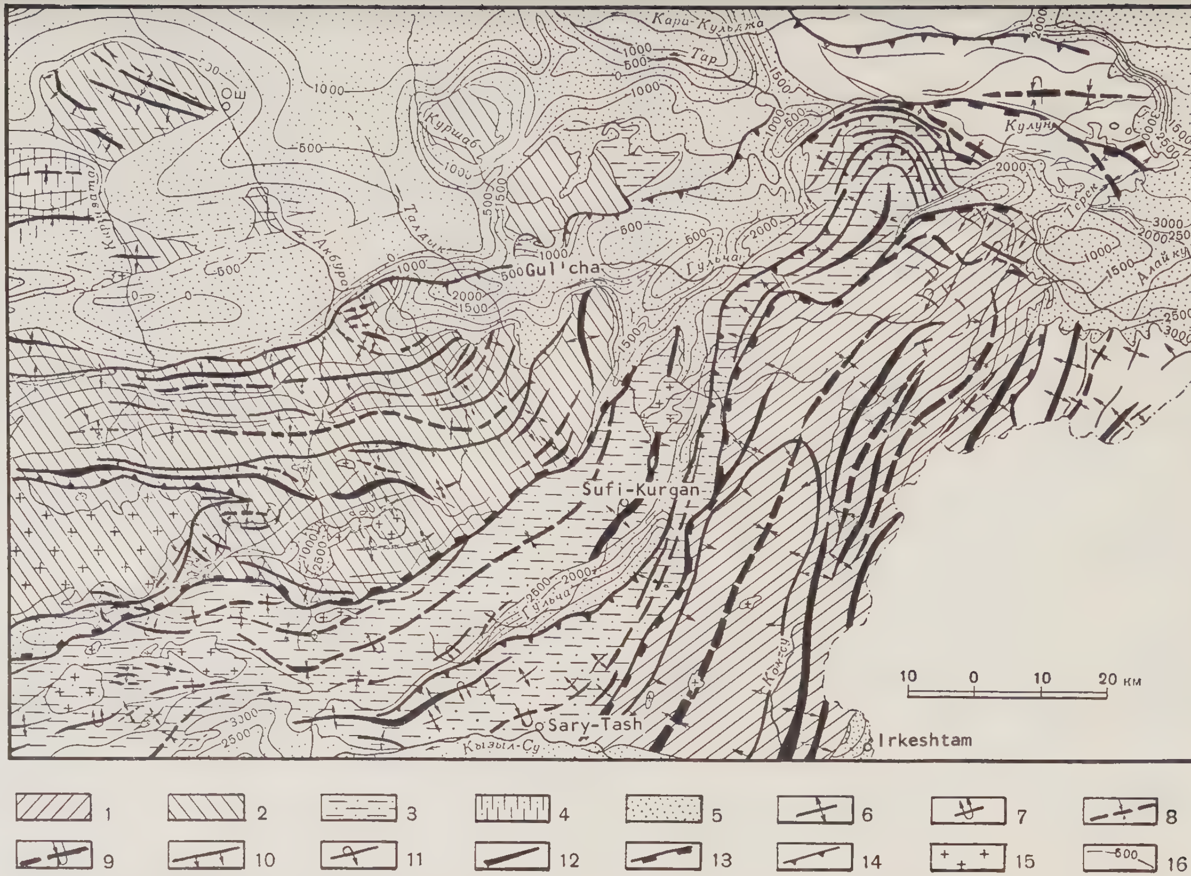

Fig. 2. Schematic representation of structural and facies zones of the Paleozoic basement of the East Alay Range.

Subzones of the first type -- early (?) to middle Paleozoic structural basins (geosynclines of second order) inverted into late Paleozoic elevations (geosynclines of the second order): 1-of Zeravshan-Eastern Alay; 2-of the Vysokiy range.

Subzones of the second type -- early (?) to middle Paleozoic elevations (geanticlines of the second order) inverted into late Paleozoic structural basins (geosynclines of the second order): 3-of Gulcha; 4-of Kara-Chatyr; 5-Mesozoic and Cenozoic blanket; 6-anticlines; 7-overturned anticlines; 8-synclines; 9-overturned synclines; 10-monoclines; 11-overturned monoclines; 12-plunging anticlines and emerging synclines; 13-deep faults; 14-other faults; 15-granitoid intrusives; 16-contour lines (drawn at 500 meter intervals) on the top of the Paleozoic basement overlain by Mesozoic and Cenozoic strata.

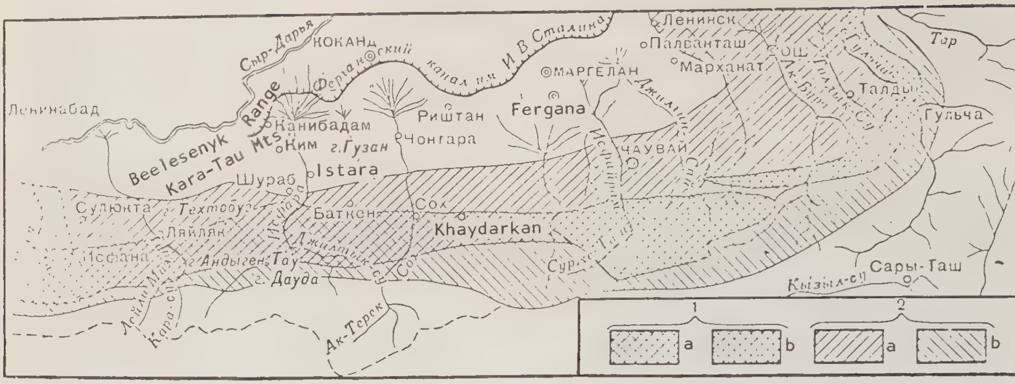

Fig. 3. Schematic representation of the principal Paleozoic structural facies subzone of the Vysokiy Front Range in the Turkestan-Alay mountain system.

1 -- Central synclinorium, the region of subsidence in the middle Paleozoic: a) middle Paleozoic structural basin inverted into upper Paleozoic elevation; b) the areas of middle and late Paleozoic subsidence. 2 -- The area of a sharply differentiated middle Paleozoic basin inverted into a general late Paleozoic elevation: a) northern anticlinorium; b) southern anticlinorium.

8 to 10 times less than that in the subzone of Zeravshan-Eastern Alay and three to five times less than that in the subzones of the Vysokiy front range. Along with decreased thickness, the middle Paleozoic section becomes rich in coarse clastic sediments, even in conglomerates, and various Silurian, Devonian, and Lower Carboniferous horizons disappear. In places the middle Paleozoic section has only Silurian beds.

The upper Paleozoic strata in the Kara-Chatyr subzone are thicker than those in the Gulcha subzone and range from 3 to 6 kilometers in thickness. However, only the southern margin of the Kara-Chatyr subzone can be observed, for its central and northern parts are overlain by Mesozoic and Cenozoic sediments of the Fergana basin. Unquestionably, the central part of the Gulcha subzone has thinner and coarser-grained middle Paleozoic sediments than those within its visible southern margin. However, even within the southern margin the middle Paleozoic sediments are thinner and coarser-grained than elsewhere in subzones of the second type; the Silurian section consists of coastal and lagoon facies, but the three Devonian subdivisions are frequently absent; the Lower Carboniferous (Namurian) occurs part in the form of coarse clastic accumulations.

Despite large interruptions in sedimentation and deep erosion that indicate Middle Paleozoic movements, no folds of this age are present within the subzones of the second type. The erosion must have been caused by epirogenic movements; various stratigraphic units of middle and upper Paleozoic sediments overlie Silurian beds without recognizable angular unconformity.

Both subzones of the second type are Caledonian-Early Hercynian (pre-Middle Carboniferous) structures, broad but sharply pronounced upwarps, separating the adjacent structural basins of the subzones of the first type.

No magma eruptions of Middle Paleozoic age are known in the area of the Gulcha subzone. Within the visible part of the Kara-Chatyr subzone, basic and intermediate lava flows occurred until the end of the Middle Devonian. Intrusives of early and middle Paleozoic age are not known in either subzone.

As in the subzones of the first type, the form of oscillations within the subzones of the second type changed abruptly at the beginning of the Middle Carboniferous. However, inversion here was opposite to that of the subzones of the first type; the subzones of the second type that were early and middle Paleozoic elevations became late Paleozoic basins. The subsidence permitted the accumulation of a thick upper Paleozoic layer in the entire area of the subzones of the second type.

The thickness, composition, and structure of the upper Paleozoic sediments are almost identical in both subzones of the second type.

The Middle and Upper Carboniferous is marked in both subzones of the second type by the accumulation of very thick, continuous, flysch-like strata of interbedded sand-

CORRELATION OF THE STRUCTURAL AND FACIES SUBZONES IN THE TURKESTAN-ALAY MOUNTAIN SYSTEM

Zones of the Southern Tien Shan

Age	Subzone / Overlying Sediments	Zeravshan-Eastern Alay			Northern High Front Ranges of the Turkestan-Alay Mountain System			Gul'cha			Kara-Chatyr		
			Jurassic			Jurassic			Cretaceous			Jurassic	
Upper Permian		P_2	Absent		P_2	Absent		P_2	Absent		P_2	Absent	
Lower Permian		P_1^2			P_1^2		Granodiorites, granites, granite-porphyry	P_1^2	Conglomerate; sandstone 300-800 m	Granodiorites, granites, granite-porphyry	P_1^2	Conglomerate, sandstone, shale, locally with enclosed limestone beds; 300 to 1,500 m	Granites-granodiorites
	Schwagerina Unit	P_1^1	Usually absent; locally conglomerate sandstone and clay layers		P_1^1	Usually absent; locally carbonate and shale layers		P_1^1	Limestone with enclosed limy shale 300 to 1,000 m thick		P_1^1	Limestone, siltstone, shale 800 meters thick	
Upper Carboniferous	Pseudo Fusulina Unit	C_3^2	Absent (?)	Granodiorites, granites, alkaline intrusives	C_3^2	Absent		C_3^2	Interbedded sandstone, shale, and silicious shale with thin beds of limestone and conglomerate, 400 to 700 meters thick		C_3^2	Shale and sandstone with limestone beds 1,500 to 1,700 meters thick	
	Triticites Unit	C_3^1	Conglomerate shale and sandstone stratum 0 to 800 m thick		C_3^1	Conglomerate beds with enclosed sandstone and shale, 500 to 2,000 meters thick		C_3^1		Basic & intermediate effusives	C_3^1	Conglomerate, sandstone, shale, 500 to 800 meters thick	
Middle Carboniferous	Zone: Fusulinella Fusulina	C_2^2	Almost everywhere absent		C_2^2	Sandstone and shale unit with enclosed conglomerate beds 400 to 3,000 meters thick	Occasional granitoid intrusives (?)	C_2^2	Flysch-like silt and shale group with enclosed sandstone, conglomerate, limestone, and porphyry; 3,500 to 4,500 meters thick		C_2^2	Sandstone and shale with thin limestone beds, conglomerate at the base; 1,000 to 1,500 meters thick	Weakly developed basic & intermediate exclusives
	Zone: Profusulinella Staffella	C_2^1			C_2^1	Almost everywhere absent. In the upper Isfairam and Chauvay Basins limestone 100 to 1,000 meters thick		C_2^1			C_2^1		

CORRELATION OF THE STRUCTURAL AND FACIES SUBZONES IN THE TURKESTAN-ALAY MOUNTAIN SYSTEM (Continued)

Lower Carboniferous	Namurian	C_1^n	Almost everywhere absent	Small basic and ultrabasic intrusives	C_1^n	Dark limestone, shale, bituminous beds locally pass into sandstone and shale units (tens of meters) 0 to 1,200 meters thick	Small basic and ultra-basic intrusives	C_1^n	Light colored limestones, variegated bedding locally, perhaps replaced by clastic sediments; 0 to 1,000 meters thick	Small basic & ultrabasic intrusives	C_1^n	Sandstone, sandy limestone, shale and silicious shale, and conglomerates; tens of hundreds of meters thick	Small basic and ultra-basic intrusives
	Visean	C_1^v	Occasional remnants represented by massive or stratified limestone (Visean) 0 to 400 m. In the Basin of the Zeravshan River, Namurian limestone in sandstone and conglomerate facies 700-750 m thick		C_1^v	Light to dark limestone differentially laminated, up to 1,500 meters thick		C_1^v			C_1^v	Limestone up to 2;000 meters thick	
	Tournaisian	C_1^t			C_1^t	Almost everywhere absent; local limestone 0 to 300 meters thick		C_1^t	Absent (?)		C_1^t	Not established	
Upper Devonian	Famennian	D_3^{fm}	Interbedded polymictic sandstone, shale, silicious shale and other rocks. Local limestone lenses 3,000 to 5,000 meters thick	Locally basic and intermediate extrusives	D_3^{fm}	Dark grey limestone, dolomitized, and dolomite or light medium-grained laminated limestone, 0 to 2,000 meters thick		D_3^{fm}	Shale and carbonate group within the greater part of the subzone replaced by terrigenous, locally coarse clastic sediments. Abundant absence of various units of Devonian; stratigraphic hiatus. Locally the entire Devonian is absent. 0 to 1,500 meters thick.		D_3^{fm}	Established only in the Guzan and Kara-Tau Mountains; Limestone and dolomite beds up to 500 meters thick	
	Frasnian	D_3^{fr}			D_3^{fr}			D_3^{fr}			D_3^{fr}		
Middle Devonian	Givetian	D_2^{gv}	Limestones locally replaced by sandstone and shale 500 to 800 meters thick		D_2^{gv}	Dark grey limestone, dolomite. In Eastern Alay, local chlorite schist with enclosed sandstone and limestone lenses, 0 to 1,500 meters thick		D_2^{gv}			D_2^{gv}	Established in a few places: in the East, chlorite schist, with enclosed extrusives and limestone up to 500 m; in the West-carbonate layer up to 700 m	Basic and intermediate extrusives
	Eifelian	D_2^e			D_2^e	Almost everywhere absent. Occasional grey limestone, 0 to 170 meters thick		D_2^e			D_2^e	Absent (?)	

CORRELATION OF THE STRUCTURAL AND FACIES SUBZONES IN THE TURKESTAN-ALAY MOUNTAIN SYSTEM (Continued)

System	Stage	Index	Subzone	Magmatism	Index	Subzone	Magmatism	Index	Subzone	Magmatism	Index	Subzone	Magmatism
Lower Devonian	Coblenzian	D_1^c	Limestone with enclosed shale. 0 to 1,000 meters thick	Locally basic and intermediate extrusives	D_1^c	Carbonate stratum at northern and southern margins of subzone, rich in rock fragments and in Eastern Alay in extrusives (porphyry diabase, spilite, and their tuffs) and silicious shale; 0 to 400 meters thick; in Eastern Alay even 1,000 meters	Local, in places extensive (Eastern Alay) basic & intermediate extrusives	D_1^c	Shale and carbonate group within the greater part of the subzone replaced by terrigenous, locally coarse clastic sediments. Abundant absence of various units of Devonian; stratigraphic hiatus. Locally the entire Devonian is absent. 0 to 1,500 meters thick	Small basic & ultrabasic intrusives	D_1^c	Almost everywhere absent. In the Kara-Chatyr Mountains--porphyry, diabase, their tuffs, and shale 1,000 to 1,300 meters thick	Basic and intermediate extrusives
	Gedinnian	D_1^g			D_1^g			D_1^g			D_1^g		
Silurian	Ludlovian	S^{ld}	Sandstone and shale, Shale and limestone strata 10 to 11 km thick. In Eastern Alay, basic extrusives and their tuffs in the lower parts of the strata		S^{ld}	Black and green graptolitic shale with thick lenses of limestone, 2,500 meters thick		S^{ld}	Limestone and shale group, replaced by terrigenous, sometimes coarse clastic sediments. Absence of thick stratigraphic units and divisions is typical. 1,000 to 1,500 meters thick		S^{ld}	Sequence of grey sandstone and shale; lenses of limestone 1,100 meters thick	
	Wenlockian	S^w			S^w	Gray shale with enclosed limestone. In Wenlockian, enclosed sandstone and porphyry (rare). Over 1,000 meters thick		S^w			S^w	Sandstone and shale, coal beds, coal-bearing shale; locally, gypsum-rich rocks 1,000 meters thick	
	Llandoverian	S^{ln}			S^{ln}			S^{ln}			S^{ln}	Extrusive and shale layers: shale, sandstone, porphyry, tuffaceous sandstone, over 1,000 m thick	
Ordovician	Caradocian	O^c			O^c	Argillite stratum and carbonaceous shale with enclosed beds of silt, sandstone, limestone, and lenses of conglomerate, 650 to 700 meters thick		O^c	Sericite and sericite-quartz schist with enclosed brecciated limestone and gravel beds 800 to 1,000 meters visible thickness		O^c	Not exposed	
	Llandeilian	O^l			O^l			O^l			O^l		
	Arenigian	O^{ar}			O^{ar}			O^{ar}			O^{ar}		
	Tremadocian	O^t			O^t			O^t			O^t		
Cambrian	Upper	Cm_3	Not exposed		Cm_3	Absent (?)	Extr. of int. & basic rocks	Cm_3	Not exposed		Cm_3		
	Middle	Cm_2			Cm_2	Shale and silicious shale, sandstone, bituminous limestone, local porphyry and extrusives of dunite composition; 600 to 1,200 meters thick		Cm_2			Cm_2		
	Lower	Cm_1			Cm_1			Cm_1			Cm_1		
Proterozoic	Upper	Pt_2			Pt_2	Not exposed		Pt_2			Pt_2		
	Lower	Pt_1			Pt_1			Pt_1			Pt_1		

1- 2- 3- 4- 5- 6- 7-

1) sharp angular unconformity; 2) considerable angular unconformity; 3) weak angular unconformity; 4) transgressive overlap and erosion but no angular unconformity; 5) type of contact unknown; 6) overlap conformity; 7) maximum depth of erosion during the respective age and consequently the unit overlies the older beds.

stone, shale, and conglomerate with subordinate limestone. The total thickness of these strata in theGulcha subzone is 4 to 5 kilometers; it is 3 to 4 kilometers in the Kara-Chatyr subzone. It must be noted that the greater part of the above strata in the Gulcha subzone is of Middle Carboniferous age but is Upper Carboniferous in the Kara-Chatyr subzone. The upper Paleozoic section in the subzones of the second type ends with Lower Permian sediments. The Lower Permian in the subzones of the second type consists of two units: the lower unit, which includes the Schwagerina formation, consists of shale and limestone 300 to 1,000 meters thick, and the upper unit consists of coarse clastic sediments, largely conglomerate 300 to 1,500 meters thick; the lower unit conformably overlies the Upper Carboniferous, but at the base of the upper unit there is a stratigraphic hiatus because of which even Devonian or Silurian beds may contact it.

The inversion of the early (?) to middle Paleozoic elevations of the subzones of the second type to late Paleozoic basins was not accompanied by folding, although deep erosion can be observed everywhere. The upper Paleozoic sedimentation was interrupted by tectonism only in the Early Permian (between the lower and upper units of this group). The tectonism led to deep erosion and locally to angular unconformity reaching 10 degrees.

The geosynclinal stage of development of the subzones of the second type ended with Late Permian (?) folding that everywhere produced an angular unconformity between Paleozoic and Mesozoic strata. This tectonism formed the principal Paleozoic structures within the subzones of the second type and eliminated the geosynclinal sedimentation within their areas.

Thus the Paleozoic folds within the subzones of the second type were formed later than those in the subzones of the first type; they were formed by Late Permian tectonism but were also affected by Early Permian movements.

The magmatic activity within the subzones of the second type, as in the subzones of the first type, depended entirely on tectonism: the small basic and ultrabasic intrusions seem to be related to pre-Middle Carboniferous tectonism; in the Middle Carboniferous, when subsidence started, basic and intermediate dikes were emplaced; finally, the geosynclinal development ended with the intrusion of large masses of acidic magma in the subzones of the second type, which, in contrast to the development in the subzones of the first type, took place during the final, Late Permian (?) phase of Hercynian folding.

The Hercynian fold structures within both subzones of the second type are complicated but distinct anticlinoria which were formed in areas of Middle Paleozoic elevations.

In the Gulcha subzone, the general anticlinal structure is clearly expressed. In the Eastern Alay, which is the central part of the subzone, a large anticline trends parallel to the valley of the Gulcha River. The anticlinal axis extends from the mountain pass of Taldyk to Sufi-Kurgan and continues to the mouth of the Chon-Bleuli River. The Taldyk anticline branches into two parts, separated by an Alpine graben of the Gulcha depression that trends at a sharp angle to the anticlinal axis. Both margins of the Gulcha subzone are synclines surrounding the central anticline and are much smaller than the anticline. This means that the Hercynian structure of the Gulcha subzone as a whole is anticlinal (Figure 2).

The Hercynian structure of the Kara-Chatyr subzone as a whole is hard to define, for only the southern margin of the subzone is exposed from beneath the Mesozoic and Cenozoic blanket and here we can see only a part of the Hercynian folds cut by numerous faults. The composite structure of the subzone is a synclinal. This can be seen at the eastern end of the southern margin of the Kara-Chatyr subzone, in the area of the Kara-Chatyr Mountains. However, it can be assumed that the central part of the Kara-Chatyr subzone, overlain by sediments of the Fergana Valley, is the highest elevated and most deeply eroded part of a Middle Paleozoic anticlinorium. In this case, the Hercynian structure of the Kara-Chatyr subzone as a whole, like that of Gulcha, is an anticlinorium whose central anticline is flanked by subordinate marginal synclines.

Thus, the inversion of Early to Middle Paleozoic elevations to Late Paleozoic structural basins within the subzones of the second type was not accompanied by folding; both Caledonian and Hercynian structures retained anticlinal characteristics.

CONCLUSIONS

In conclusion, let us underline the principal patterns that controlled the geosynclinal development and determined the structural and facies zoning of the Turkestan-Alay mountain system in the Paleozoic:

1. Within the Turkestan-Alay mountain system two types of structural and facies subzones, whose Paleozoic history and

geologic makeup differ greatly, can be distinguished (Figure 1).

The subzones of the first type, those of Zeravshan-Eastern Alay and of the Vysokiy front range, were subsidences (geosynclines of the second order) in the lower (?) to middle Paleozoic but turned into elevations (geanticlines of the second order) in the late Paleozoic.

The subzones of the second type, those of Gulcha and Kara-Chatyr, on the contrary, were elevations (geanticlines of the second order) in the early (?) to middle Paleozoic that turned into basins (geosynclines of the second order) in the late Paleozoic.

2. Each subzone retained its autonomous position during the entire Paleozoic, and the specific structural and facies characteristics of each zone remained different from those of others. The boundaries of the subzones were not displaced laterally despite the fact that the tectonic and sedimentation conditions instantly changed within each of them at the turn of the middle Paleozoic into the late Paleozoic. The changes in adjacent subzones were not only dissimilar but of opposite directions: at the turn of the middle Paleozoic to late Paleozoic, in the subzones of the first type geosynclines were inverted to geanticlines, while in the subzones of the second type the inversion was exactly the opposite.

3. The different course of the principal epirogenic movements in the different subzones determined the different development of all other geologic processes, and this in turn was the cause of the differing composition of the Paleozoic strata in the subzones concerned.

The differences in composition and structure are:

a) The subzones of the first type have thick lower (?) to middle Paleozoic sections consisting of shale, extrusive, and carbonaceous layers deposited on the floor of an open sea. On the other hand, upper Paleozoic sediments are absent in large areas of the subzones of the first type. If they occur, they occupy only local depressions and consist of coarse clastic sediments. They are thin, the stratigraphic columns are incomplete, and a number of units disappear.

The Paleozoic sections within the subzones of the second type are the opposite of those of the first type: lower (?) to middle Paleozoic columns are incomplete, thin, and most frequently consist of coarse clastic sediments. Upper Paleozoic formations, on the other hand, occur extensively in the form of thick flysch-like strata.

b) The Paleozoic fold structures within the subzones of the first type are of Lower Permian age and are to a certain degree affected by pre-Late Carboniferous movements, while the structures of the subzones of the second type are younger: they were formed in the Late Permian and affected by Early Permian tectonism.

All the Paleozoic structures are younger than the above-mentioned epirogenic movements that caused erosion (in places deep erosion) and stratigraphic disconformity but nowhere regional angular unconformity.

c) They conform with the differing age of folding and magmatic activity which developed differently in different subzones.

During the general subsidence (early Paleozoic in the subzones of the first type and the Upper Paleozoic in the subzones of the second type), submarine eruptions of basic and intermediate extrusives took place.[1]

By the end of the Paleozoic, synchronously with the principal phase of folding in the geosynclinal development, large masses of acidic magma were intruded the subzones of the first type during the Early Permian and the subzones of the second type in the Late Permian (?).

No other parts of the Paleozoic sections of the subzones of both types contain intrusives except for small dikes of basic and intermediate composition. The dikes seem to have been intruded at the turn of the Early Carboniferous to Middle Carboniferous, when geosynclinal subzones turned into elevations and vice versa.

d) The scheme of development of fold structures in the subzones of the Turkestan-Alay mountain system is as follows:

In early (?) to middle Paleozoic time, the subzones of the first type subsided continuously in the form of a syncline; the amplitude of subsidence was greater in the central part than at margins of the subzones. Between the Early and Middle Carboniferous, the general subsidence of the subzones of the first type ended, being replaced by elevations. However, the Hercynian fold structures within the subzones of the first type

[1] The presence of Silurian and Devonian extrusives in the Kara-Chatyr subzone is probably explained by the fact that they occur only in the marginal part of the subzone where it joins the subzone of the Vysokiy front range.

did not develop until the end of the Paleozoic; clearly expressed synclinoria were formed early in the Permian.

Thus, the principal inversion of epirogenic movements between the middle and upper Paleozoic (between the Early and Late Carboniferous) did not produce any folds in the subzones of the first type; their Caledonian and Hercynian structures remained of synclinal type.

In the subzones of the second type, elevations generally of anticlinal type developed in the early to middle Paleozoic; the amplitude of elevation increased from the margins to central parts of the subzones.

Between the Early and Middle Carboniferous, the general elevation of the subzones of the second type was reversed into general subsidence. The Hercynian structure, formed from the subzones of the second type after the late Paleozoic subsidence, are early Late Permian anticlinoria. Thus, the principal inversion of epirogenic movements that took place between the middle and late Paleozoic (between Early and Middle Carboniferous) did not cause folding within the subzones of the second type; the Caledonian and Hercynian structures remained of anticlinal type.

e) The reversal of the direction of epirogenic movements in the subzones of both types did not lead to inversion of the bottom of fold structures, for the late Paleozoic elevation of the subzones of the first type and the simultaneous subsidence of the subzones of the second type occurred along deep faults terminating the subzones. Thus, the subzones of the Turkestan-Alay mountain system moved up or down as single blocks of tremendous size along terminating fault planes.

f) All the subzones of the Turkestan-Alay mountain system are terminated by deep faults. All of them are well-established on geologic maps. The Mesozoic and Cenozoic strata are also displaced along these marginal deep faults. However, the amplitudes of the Alpian displacements along them do not exceed a hundred meters, whereas the displacement of Paleozoic sediments reach kilometers.

4. The Paleozoic geosynclinal zone of Southern Tien-Shan has subzones that differ from those of the Turkestan-Alay mountain system; there are subzones of a third type, geosynclines of second order during the entire Paleozoic, and subzones of a fourth type -- geanticlines of second order -- during the entire Paleozoic. The Fergana Range between the Tar and Urumbash Valleys seems to represent the former type of subzone, and the Suluterek massif, an exposure of the Precambrian basement between the Eastern Alay and the Fergana Range -- partly beyond the Soviet boundaries within the northwestern Kashgar Province -- is an example of the latter type.

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CONJUNCTION OF THE MONGOL-OKHOTSK AND PACIFIC FOLD ZONES WITH THE CHINA PLATFORM

by

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The geologic data on the Manchurian fold zone of the Mongol-Okhotsk Belt and the northeastern China platform may confirm the concept that during the Caledonian cycle there was a northern projection of the platform which, in the Middle Paleozoic, turned into a geosyncline and late in the Permian joined the fold zone.

* * * * *

The southern part of the Soviet Far East and the adjacent regions of China and Korea are areas where tremendous geotectonic elements of the first order are joined together. The Siberian and Chinese platforms extend north and south of this area; the area to the east is occupied by the western branch of the Pacific fold zone; and between the platforms lies the eastern end of the Mongol-Okhotsk fold zone (Figure 1). All these geotectonic elements have complicated structures.

The zones of the Mongol-Okhotsk belt, as shown in Figure 2, are clearly distinguishable. The Siberian platform is bounded by the Salair fold zone of Proterozoic age in the south. The next zone of post-Caledonian folding to the south occupies the Transbaikal Region and eastern Mongolia, but its eastern continuation is still barely known. The middle segment of this early Hercynian fold zone does not show any traces of Caledonian tectonicsm, while in its southern segment, along the Argun Basin, a definite angular unconformity exists between the lower and middle Paleozoic sediments [2]. Thus, there is a certain symmetry in the disposition of late Caledonian and early Hercynian structures. Unfortunately, data on the Paleozoic section of adjacent districts are still inadequate to unravel Caledonian structures farther southeast. The outermost southern zone, the late Hercynian fold zone of Manchuria, trends from the eastern slope of the Great Khingan to the boundary of the Chinese platform.

The late Caledonian and early Hercynian zones are obscured by superimposed structural basins, of which one of Permian age, located within the area of early Hercynian folds of the eastern Transbaikal Region, trends from northeastern Mongolia to the interfluvial area of Shilka-Argun and is recognizable by its folded Permian geosynclinal sediments (Fig. 3) [2]. The Mesozoic belts of subsidence trend from Mongolia through the basin of the Upper Amur to the Sea of Okhotsk (Fig. 4).

Within the Sikhote-Alin branch of the Pacific belt there can be distinguished two fold zones which are, from west to east: 1) The Hercynian fold zone that formed partly during the Caledonian cycle but was also complicated by additional Mesozoic tectonic activity [1, 8]; and 2) the zone of Mesozoic folds, developed within the area of late Hercynian structures and complicated in its eastern part by Tertiary tectonic activity. The area between the two zones is occupied by the Khankai massif.

The structure of the northeastern part of the China platform and its development are not yet clear, and two different opinions exist on the subject. The northern boundary of the China platform, existing since the beginning of the Mesozoic, is known quite well except for the part covered by Mesozoic sediments within the Manchurian plain. There are good reasons to believe that the sediments within the southern and extreme northern parts of the plain rest upon a crystalline basement that seems to be a remnant of the stable China platform.

Since the publication of Yu. M. Sheynman's article [15], with which the modern concept of the composition of the China platform began, many investigators tend to extend the Lower Paleozoic platform farther north, including the supposedly stable massif underlying the basin of the Zeya and Bureya rivers. However, the area between the China platform and this massif during late Hercynian tectonism was a late Hercynian fold zone.

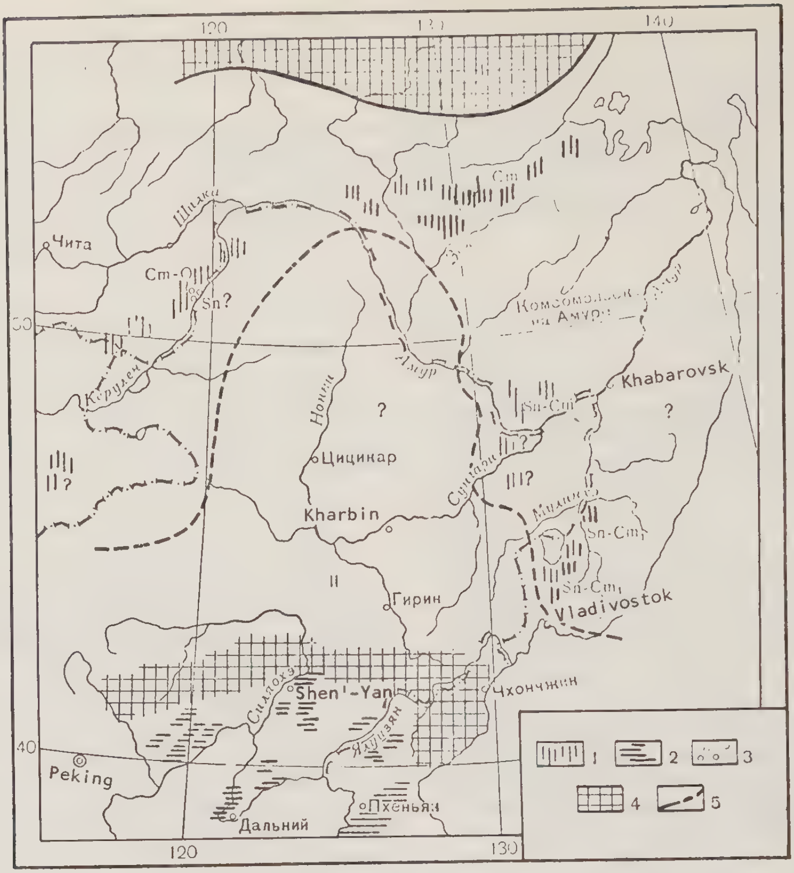

Fig. 1. Conjunction of the Mongol-Okhotsk and Pacific geosynclinal belts and of the China Platform during Sinian and Caledonian periods.

1 -- geosynclinal formations; 2 -- platform sediments; 3 -- coarse clastic (Sinian [?]) sediments; 4 -- erosional districts on platforms; 5 -- boundaries of platforms, traced, and inferred.
I -- Siberian Platform; II -- China Platform.

By now, some geologic data has become available concerning this extensive region and the northern part of the China platform [11, 17, 18, 21, 22], which was little known at the time of publication of earlier summaries [9, 10, 13]. Consequently, new geotectonic summaries must be based on these data. This article is intended to be such a summary. However, since the knowledge on the region is still incomplete, the conclusions drawn should be considered preliminary working hypotheses.

1. PRE-SINIAN DEVELOPMENT OF THE NORTHEASTERN PART OF THE CHINA PLATFORM

The China platform has two old structural units -- the Archean and Lower Proterozoic [11, 22]. Archean and Lower Proterozoic rocks occur extensively in Southern Manchuria, where they occupy the core of young elevations (the so-called crystalline massif of Jehol and the Liaosi and Liaotung Mountains) or occur in the form of isolated hills protruding from beneath unconsolidated sediments of the Liao lowland. Pre-Cambrian formations also underlie nearly horizontal Mesozoic sediments in the area of the watershed between the Sungari and Liao Rivers.

Pre-Cambrian crystalline rocks form two belts in Northern Manchuria: 1) the East Manchurian belt that extends from the Korean boundary along the Mutankiang River toward the Malyy Khingan Mountains; and 2) another belt that trends along the Amur branch of the Malyy Khingan Mountains due Northwest. Several exposures of Pre-Cambrian rocks are known along the eastern slope of the Great Khingan Mountains and in Barga.

The contact between the Archean and

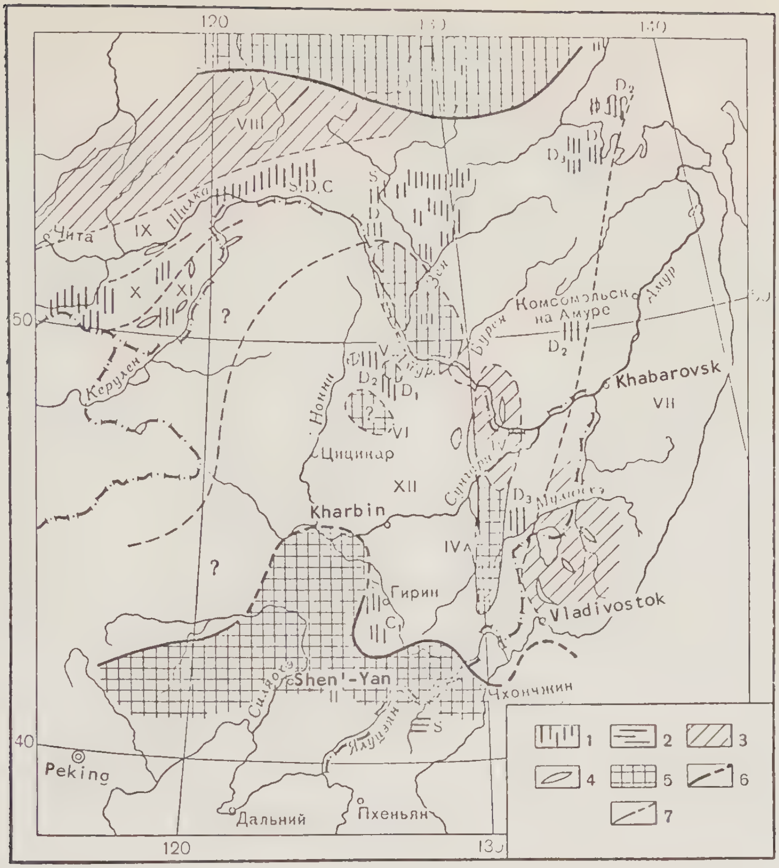

Fig. 2. Conjunction of the Mongol-Okhotsk and Pacific geosynclinal belts and the China Platform during the middle Paleozoic

1 -- Geosynclinal formations; 2 -- platform sediments; 3 -- zones of Caledonian folding; 4 -- strike of Caledonian folds; 5 -- platforms and pre-Cambrian massifs; 6 -- boundaries of platforms; 7 -- boundaries of other tectonic units.

I -- Siberian Platform; II -- China Platform; III -- Zeya Massif; IV-V -- elevations of: (IV) - Malyy Khingan, (IV-a) - Changkwangsaling, (V) - Nonni; VI -- North Manchurian massif; VII -- maritime elevation; VIII-XII -- zones of the Mongol-Okhotsk geosynclinal belt: (VIII) - zone of Caledonian volding, (IX) - North Transbaikal, (X) - Middle Transbaikal, (XI) - Argun, (XII) - Manchurian.

ower Proterozoic strata in southern Manhuria is not everywhere clearly recognizble. However, the existence of angular unonformity and stratigraphic hiatus between hem is beyond doubt. The two sections are ot defined precisely and the age of the supposedly lower Proterozoic crystalline schist s still doubtful. The top of this unit is clear ecause of the angular unconformity between and the overlying upper Proterozoic strata. ince the knowledge of Pre-Cambrian section ithin geosynclinal zones is still inadequate, n exact definition of this unit is hardly posible at the present time. Only a few expoures can be correlated with the correspondng formations known on the platform. The Archean sequence within southern Manchuria consists of gneiss frequently containing graphite, granite-gneiss, mica, and chlorite schist, amphibolite, and marble lenses. In northern Manchuria, also, the lower parts of the Mashan layers [11] are considered to be of Archean age. The structure of intricately folded Archean rocks is not yet studied. The thickness of the sequence apparently reaches several kilometers but is not yet known precisely.

The lower Proterozoic sequence in southern Manchuria consists of crystalline schist and carbonate layers that occur in the middle part of the stratigraphic section. The

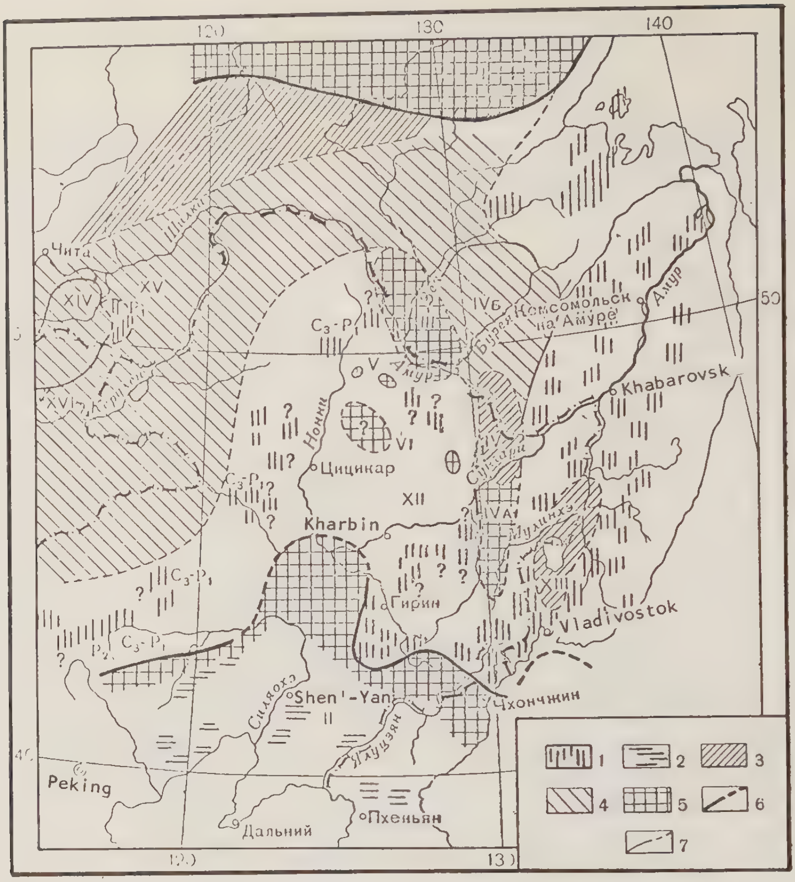

Fig. 3. Conjunction of the Mongol-Okhotsk and Pacific geosynclinal belts and the China Platform in Upper Carboniferous and Permian time.

1 -- geosynclinal formations; 2 -- platform sediments; 3 -- zones of Caledonian folding; 4 -- zones of early Hercynian folding; 5 -- platforms and pre-Cambrian massifs; 6 -- boundaries of platforms; 7 -- boundaries of other geotectonic units.

IVb -- elevation of Bureya; XIII -- Khanka geanticline; IV -- Aginsk elevation; XV - SVI -- Permian geosynclinal basin of Transbaikal and Eastern Mongolia.

crystalline schist encloses phyllite layers usually interbedded with graphite and iron ore-bearing quartzite, graphite schist, and marl lenses. The sequence also contains jaspilites near the top. The carbonate layers consist of thick dolomite beds (with Gymnosolen [18]) interbedded with phyllite, talc, and chlorite schist, and magnesite lenses. The total thickness of the lower Proterozoic in southern Manchuria reaches 18 kilometers (?).

In northern Manchuria the lower Proterozoic sequence apparently consists of the crystalline schist of the Upper Mashan series. The narrow linear folds within the lower Proterozoic sequence are well mapped in the Tashikiao district, where they trend north-northeast.

Late in the early Proterozoic, the biotite granite of Tuimianshan was intruded in the Anshan district and gabbro in the province of Jehol. Gabbro xenoliths were found in the Kungchuling granite.

The upper Paleozoic is known only within the old China platform, along a sublatitudinal strip that extends from Korea toward the Liaotung Peninsula and farther west into northern China [11, 22]. The upper Paleozoic sequence consists of interbedded phyllite, quartzite, and schist, metamorphosed to varying degrees. At the base (Anshan layers) it contains thin phyllite beds rich in hematite, iron-bearing quartzite and grunerite-cummingtonite and amphibole schist; in the middle part there occur lenses and thin beds of siliceous limestone and, finally, the top

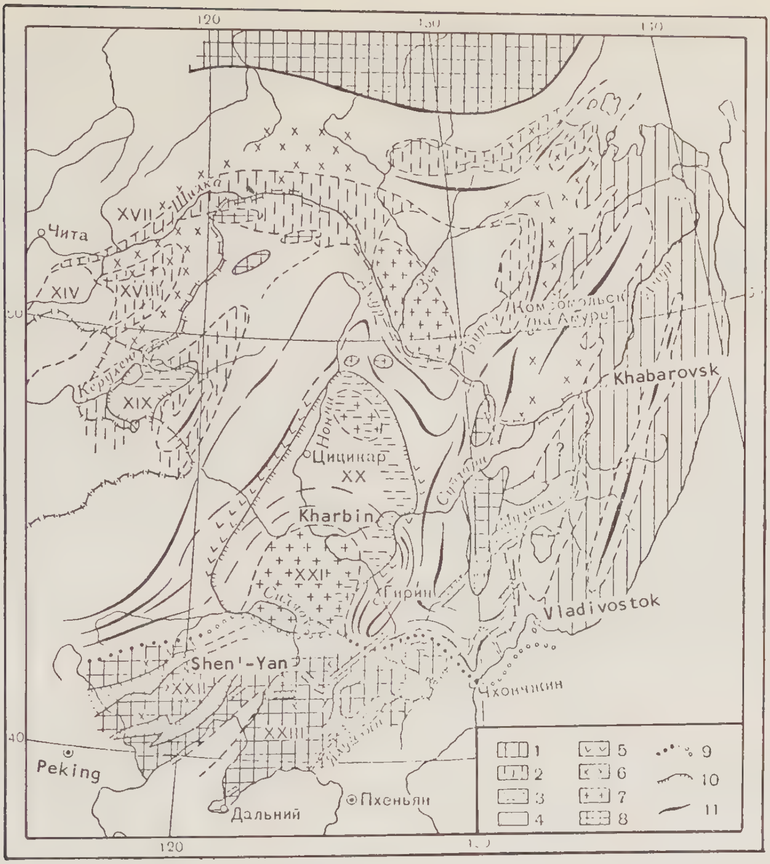

Fig. 4. Conjunction of the Mongol-Okhotsk fold zone with the China Platform and the Pacific geosynclinal belt in the Mesozoic.

1 -- geosynclinal formations; 2 -- marine, fresh-water, and volcanic formations in the basins of the Mongol-Okhotsk Belt; 3 -- continental sediments in large depressions; 4 -- continental and volcanic formations in the basins within the Manchurian fold zone and the China platform; 5 -- extrusive bodies and small intrusions of andesite, rhyolite, and porphyries; 6 -- granitoids; 7 -- pre-Cambrian massifs (of the deep basement); 8 -- shield and platform exposures of the pre-Cambrian basement in the core of fold zones; 9 -- boundaries of the rejuvenated China platform, traced and assumed; 10 -- principal faults; 11 -- strike of Hercynian fold structures.

XVII, XVIII -- Triassic and Jurassic basins in the eastern Transbaikal region; XIX -- Barga syncline; XX -- Syncline of Central Manchuria; XXI -- Central Manchurian block; XXII -- Uplifted crystalline massif of Jehol; XXIII -- Liaotung uplift.

nsists of limestone and dolomite with ollenia. The upper Proterozoic is as much s 8 kilometers thick. The bottom and top of e sequence is well defined because of reonal angular unconformities with the undering lower Proterozoic and overlying Sinian rata.

Late in the Proterozoic, pink microclinebite granite of Kungchuling was intruded and number of magnesite, iron, and other desits were formed. Late Proterozoic tecnism has not yet been studied as such; it has been considered a part of Proterozoic tectonic activity and consequently late Proterozoic structural forms are barely known. Furthermore, the boundaries of the above sublatitudinal strip of upper Proterozoic sediments have not been determined precisely. The strip may have a submeridional branch which trends from the Liaotung Peninsula due north, where it is covered by the sediments of the Manchurian plain.

Directly in this mobile zone of folded upper Proterozoic sediments, there are deep

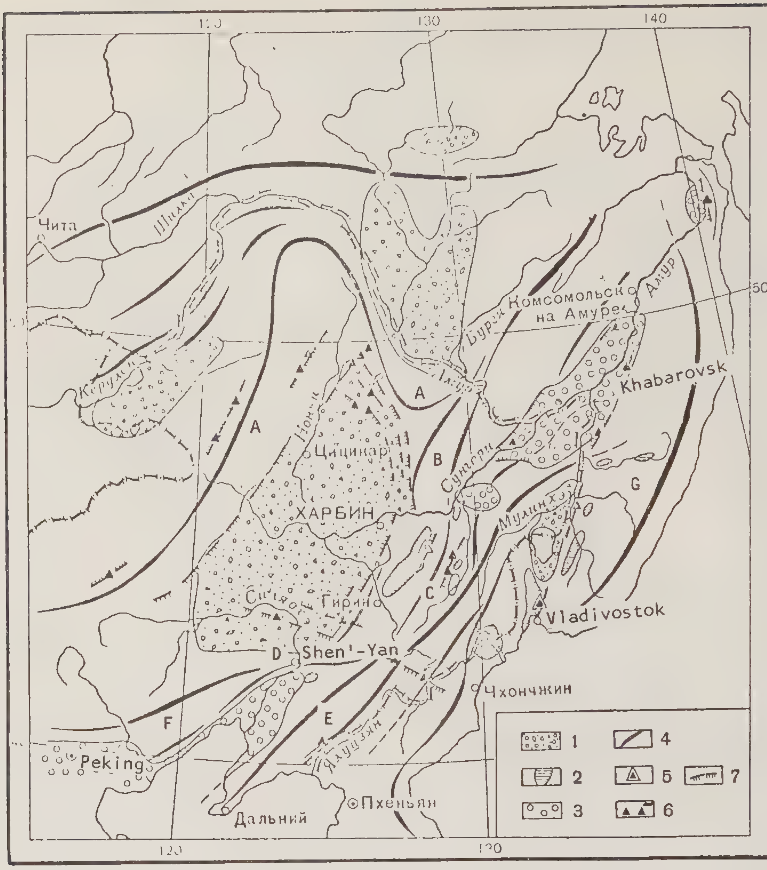

Fig. 5. The Conjunction of the Mongol-Okhotsk and Pacific fold zones and the China Platform in the Cenozoic

1 -- Tertiary-Quaternary depressions; 2 -- Tertiary basins; 3 -- superimposed Quaternary depressions 4 -- axes of uplifts; 5 -- Tertiary volcanoes; 6 -- most recent volcanoes, including those that remained active through the eighteenth century; 7 -- principal faults.

Elevations of: A -- Khingan; B -- Heichingshang; C -- East Manchuria; D -- Sunglingshang; E -- Liaotung; F -- Jehol; G -- Sikhote-Alin.

basins filled with terrigenous, carbonaceous sediments of lower Sinian-Jeholian age in the northwest and of Korean age in the northeast. In southern China, similar upper Proterozoic zones are enveloped by tillite outcrops. In southern Anhewy there is a large Early Sinian [5] basin at the margin of a Proterozoic strip. It seems that the China platform had a number of mobile zones during the late Proterozoic, where extensive sedimentation and folding took place. Consequently, these zones were formed into elevations, while the zones adjacent to the mountain ranges subsided and were possibly covered by glaciers.

By the end of the Proterozoic, the China platform finally became stabilized as a result of folding and magmatic intrusions.

2. THE CALEDONIAN STAGE OF DEVELOPMENT OF THE NORTHEASTERN CHINA PLATFORM AND THE GEOSYNCLINES SURROUNDING IT

We do not consider the upper Proterozoic sequence to be a part of the Sinian section because of angular unconformity between the two sequences and their different degree of metamorphism; in the majority of cases, the Sinian sediments are only diagenetically altered.

The Sinian section has a maximum thickness of 4 kilometers in the Jehol basin, where its lower division consists of terrigenous and carbonaceous facies that alternate with each other within the section three times

e Lower Sinian section as a whole consists metamorphosed shale, quartzite, dolomite, l siliceous limestone with Collenia cylind-a (Grabau) near the bottom [22]. The jority of geologists do not recognize the wer Sinian as we understand it, but there e indications of its existence in the litera-e. For example, in the southern Anhwey in, Lower Sinian layers 12 kilometers ck underlie tillite and overlie upper Pro-ozoic beds [5] with an angular unconformity.

The Upper Sinian overlies the Lower Sin- with a stratigraphic disconformity and dually passes from continental, possibly n desert formations of red or multi-ored sandstone, conglomerate, argillite, l marl to coastal and marine sandstone, ceous shale, dark argillite, and limestone h Collenia fuchouensis Resser et Endo. e thickness of the Upper Sinian does not eed 700 meters.

The lower Paleozoic sequence, 600 to 00 meters thick, overlies the Sinian trans-essively and begins with red coastal argil-e of the Lower Cambrian that contains nts of rock salt crystals and lenses of estone containing Redlichia. Higher there e marine argillite and limestone of the ddle and Upper Cambrian. The Upper mbrian fauna is of Pacific type. Ordovician ls resting upon an erosional surface con-t of limestone (commonly siliceous), argil-e, and dolomite with a boreal fauna. Ac-rding to the monograph by Lee Sy-Huan [5], depressions developed in northern China Sinian time, that of Shensi and Taishan-ntung, separated by the Liulian upwarp. ey developed still further in the Paleozoic extended due northeast into the Jehol vince and the Liaotung Peninsula. The ian and lower Paleozoic sediments die out the north and their geosynclinal analogues known only in the eastern Transbaikal ion, in the Soviet Malyy Khingan, in theastern Manchuria, where Sinian-Cam-an beds were found by Yu. A. Khodak in Tszyamus district, and in the western t of the Primor'ye Province. The geosyn-nal Lower Paleozoic sequence in the east- Transbaikal region overlies intensively tamorphosed pre-Cambrian beds with ular unconformity. The lower Paleozoic pre-Cambrian strata change their strike m northeast to meridional in the eastern nsbaikal region; it is latitudinal in the kuringer-Dzhagda Mountains, while the nbrian extends meridionally in the Malyy ngan Mountains. In the Primor'ye Prov-e the Caledonian structures involving ian-Cambrian strata strike northwest to east and southeast of Lake Khankai and ridionally south of the lake.

The Sinian-Lower Paleozoic beds are thus far not known in the zone of Late Hercynian folding. This can be a result of inadequate knowledge of the geology of the area, but it is also possible that they are really absent because of continental conditions during this long period.

If the latter assumption is correct, the China Platform had a northern projection during the Caledonian geosynclinal period. This assumption seems to be correct because of lateral distribution of the lower Paleozoic geosynclinal facies and the coarse-clastic nature of the upper pre-Cambrian (perhaps Sinian) in the Transbaikal region. The Caledonian structures striking parallel to the boundaries of the assumed northern projection of the China platform surround this projection at the northwest, north, and northeast, and this fact supports the above concept (see Fig. 2). As a result of Caledonian tectonism, the Sikhota-Alin elevation [1] emerged, as apparently did the axial part of the Bureya elevation. Since the Caledonian distrophism, the southern part of the Mongol-Okhotsk geosyncline (Manchurian) occupied the area west of the Sikhote-Alin elevation.

3. THE HERCYNIAN STAGE OF DEVELOPMENT OF THE NORTHEASTERN CHINA PLATFORM AND THE GEOSYNCLINES SURROUNDING IT

Since the end of the Ordovician, the northern China platform has been emergent for the greater portion of time. During the entire middle Paleozoic, it was affected by continental conditions. This is evident because of the complete absence of marine sediments and an erosional surface upon which upper Paleozoic sediments were deposited. Only along the margins of the platform, such as in northern Korea, did small transgressions take place [11]. Upper Paleozoic strata rest on an erosional surface at the top of the Ordovician. Angular unconformities are present locally, as in northeastern Jehol and Nanpiau. The Upper Paleozoic section of southern Manchuria begins with variegated sandstone and shale of the Middle Carboniferous, at the base of which occurs a bauxite bed with iron concretions and interbedded marine limestone. Basal conglomerate is present locally. The Middle Carboniferous sediments are overlain with slight stratigraphic disconformity by coal-bearing Upper Carboniferous and Lower Permian beds that contain limestone in the lower part and beds of bauxite and refractory clay near the top. These, in turn, are overlain by unfossiliferous red argillite and cross-bedded sandstone, the age of which is presumably Early Permian to Triassic [17, 21]. The Upper Paleozoic strata on the platform are 750 to 1,000 meters thick.

In northern Manchuria only geosynclinal facies of Paleozoic sediments are known. We consider the highly folded, diagenetically altered, and metamorphic formations to be of middle Paleozoic age. This sequence consists of three groups: a) marine terrigenous sediments now represented by phyllite schist and quartzite with interbedded graywacke, conglomerate, and limestone lenses; b) very typical siliceous extrusives composed of siliceous shale, jasper-like and various siliceous sedimentary rocks, blankets of porphyries -- with or without quartz, felsite, and their tuffs; c) a spilite sequence which is less extensive and consists of spilite, diabase, and porphyry [11].

Fossiliferous layers, largely carbonates, are rare but occasionally are known to contain a marine fauna of Gotlandian, Lower, Middle, and Upper Devonian and Lower Carboniferous age. The middle Paleozoic sequence is several kilometers thick. It is still not known how it is overlain by upper Paleozoic rocks. In the Mingcheng district (south of the city of Kirin), black Upper Visean shale with interbedded limestone underlie without visible disconformity rocks of similar composition but containing Permian and Carboniferous fauna. No angular unconformity between the middle and upper Paleozoic strata was noticed. On the other hand, some observations point to the possibility of local movements and to stratigraphic interruptions between the two sequences. For example, nowhere in the upper Paleozoic section thus far have middle and upper Carboniferous sediments been discovered. The middle Paleozoic sequence has, if anything, only weakly developed spilites and siliceous extrusive formations. However, the tectonics of northern Manchuria are still so little known that the possibility of unconformities within the lower Paleozoic section must exist. The secondary geosynclinal zone of Manchuria, now a part of the Mongol-Okhotsk Belt, was most likely superimposed upon the northeastern projection of the China platform early in Silurian time.

Since there are no fossiliferous middle Paleozoic sediments in the Province of Primor'ye (which occur, however, farther east in Japan), we may assume that the province was rising after the Caledonian folding [1]. This elevation was possibly caused by the subsidences of the newly formed Manchurian zone of structural basins.

Differential subsidence within the Sikhota-Alin elevation started again in the Carboniferous, when the geosynclines of Grodekov and Sikhote-Alin, separated by the Ussuri-Khankai geanticline, were formed. In the Province of Primor'ye, volcanic facies were formed in the late Paleozoic [1]. The Late Paleozoic subsidence could hardly be produced by typica inversions in the sense of V.V. Belousov, fo parts of the Ussuri-Khankai elevation continued to rise. The rearrangement of the structural pattern is, however, beyond doubt, since northeast to meridionally-striking Hercynian structures were superimposed on northwesterly and meridional Caledonian structures.

In northern Manchuria, the geosynclinal upper Paleozoic section begins with transition Permian and Carboniferous strata overlain by Lower and Upper Permian beds. Here marine terrigenous sediments consisting largely of shale, siltstone, and sandstone are most extensive and enclose thin layers of conglomerate, limestone, and, rarely, tuffs. Extrusive rocks are known only in the extreme eastern part of the Manchurian zone, where it joins the Sikhote-Aline geosyncline [17]. The Lower Permian limestones locally (for example, east of Kharbin contain fluorite concretions that suggest existence of an isolated sea basin [11].

The Upper Paleozoic section is less metamorphosed toward the top; the Permian and Carboniferous section still has a few metamorphosed sandstone and shale beds, but in the Lower Permian there are only slightly recrystallized limestones; and finally, the Upper Permian is practically free of traces of metamorphism (e.g., Dabasu-Sume formation south of the Great Khingan). The Dabas-Sume formation overlies the Lower Permian Utsumuchin layers with angular unconformity.

The final phase of Hercynian tectonism in the Manchurian zones took place after the deposition of Upper Permian sediments. This tectonic phase cannot be dated precisely because of a stratigraphic hiatus between the Upper Permian and Upper Triassic sediments which overlie the former with angular unconformity.

The age of the Hercynian tectonic activity in Barga and along the western slope of the Great Khingan cannot be determined even approximately, but by assuming its equivalence with the tectonic phase of eastern Transbaikal, we consider it to be early Hercynian.

Biotite-amphibole granite and diorite were intruded in the Lower Permian limestones in the Pansha and Siaoling district. Biotite granite of Khabutu that occur in western Manchuria and Mongolia are also believed to be of Hercynian age. Granitoids form large batholiths (e.g., on the western slope of the Changkwangsaling) as do other intrusives whose composition is still inadequately known.

Apparently, by the end of the Paleozoic ensive sills and small intrusions of quartz quartz-free porphyries were emplaced ng the western and eastern slopes of the t Manchurian mountains. Quartz porphyry s containing xenoliths of overlying rocks e intruded in the Upper Paleozoic section, t of Kharbin, where gentle folds of northterly strike were formed. Here also oc- numerous laccoliths (e.g., of Maoershan), ch apparently are younger, perhaps even Mesozoic age, but along with sills form a that trends due northwest for about 60 meters up to the boundary of the Manrian Plains.

The Hercynian structures have not yet been died, but their occurrence in the form of ar folds is beyond doubt. The folds are ge, several kilometers wide, and have gentle and steep limbs.

The Paleozoic strata in the Inshan system ke generally latitudinally and plunge er the sediments of the Manchurian Plains he east. The principal structures in the an system curve to the northeast and join Hercynian structures of the Great Khingan strike north-northeasterly. Here we apently have virgation. East of the Manchur- mountains, another kind of virgation is cated. Here Hercynian structures in the gcheng districts (south of Kirin) and Yagou st of Kharbin) strike northeasterly in the th, but turn northwesterly in the north . The northwesterly strike also prevails ng the western slope of the Changkwangng, while along the central part of this ge meridional strikes are most common.

Paleozoic outcrops and granitoid intrusions Hercynian age surround the pre-Cambrian e of the east Manchurian mountains from west and east. Sporadic observations ng the Amur branch of the Malyy Khingan untains permit us to assume that Hercy- structures in this region generally strike thwest and surround the pre-Cambrian e of the range. Thus an anticlinorium of first order within the east Manchurian ges becomes evident; it joins the anti- orium of the Malyy Khingan in the north. ether or not the structures of the Great ngan form an anticlinorium is still doubt- It is possible, however, that pre-Camn outcrops that extend along the eastern e of the Great Khingan Range represent eanticlinal elevation that separates the es of early and late Hercynian folds. No nection between the pre-Cambrian core he Great Khingan and those of the Amur nch of the Malyy Khingan and of the yy Shingan proper is thus far recognized. erally speaking, Hercynian folds, includ- those of Ilkhuri-Alin, form a large sig- d (northern branch of Hercynian structures of the Manchurian zone), the form of which is clearly related to the supposed pre-Cambrian basement at the base of the Zeya-Bureya depression. South of the sigmoid, at the base of the sediments of the Manchurian Plains, there is probably another part of the basement. The basement is separated from the China platform of Hercynian time by the southern branch of folds that extends along the northern projection of the platform and form arch that begins east of Kharbin and, continuing under the Manchurian Plains, joins the latitudinal branch of the Inshan virgation.

The conjunction of the Late Hercynian zones with the China platform is still speculative. The stable remnants of the platform by Hercynian fold zones are, however, evident along both the Khingan sigmoid and the southern branch of the Hercynian zones. Some Hercynian structures strike parallel to the detailed outlines of the platform. For example, south of Kirin, the Hercynian structures, whose pattern resembles a loop, form a geosynclinal bay within the platform and, extending further east, trend almost latitudinally along the northern edge of the platform [23].

A remarkable fact is the absence of marginal subsidence at the junction of the Hercynian zones and the China platform. This seems to be related to a peculiar development of the platform in the Mesozoic, when the mobile structural basins developed and were extended parallel to the boundaries of the platform.

The supposed boundary between the Mongol-Okhotsk and Pacific belts at the time of the Hercynian diastrophism extended along the western boundary of the Grodekov depression and then due north-northeast along the eastern boundary of the area of the middle Paleozoic geosynclinal sedimentation. The boundary can be traced partly because of facies differences in the upper Paleozoic sediments.

The Hercynian tectonism produced the final form of the Bureya uplift within the Mongol-Okhotsk belt and that of the middle massif of Aginsk [12]. At the same time, the final phases of folding and uplifts brought to an end the geosynclinal stage of the belt as a whole. The Grodekov depression within the Sikhote-Alin zone became elevated and the newly-formed elevation was contiguous to the east Manchurian structures of Hercynian age. The central core of the Sikhote-Alin zone itself was also uplifted [1, 4].

4. THE MESOZOIC STAGE OF DEVELOPMENT OF THE NORTHEASTERN CHINA PLATFORM AND THE GEOSYNCLINES SURROUNDING IT

In the Early Mesozoic, the northeastern part of the China platform entered a new stage of its evolution, the stage of rejuvenation during which it was divided into several stable blocks separated by mobile zones [11].

The details of rejuvenation follow: during the Triassic period, the platform broke into large structural basins and elevations, probably the result of continued elevation of folds within the Late Hercynian envelope. These structural forms, newly formed basins and elevations of the second order, became complicated by marginal faults that were generally parallel to the predominant strike of Hercynian structures within the platform. As an example, we may cite the Jehol basin that generally strikes latitudinally in the west and nearly meridionally in the northeast. This basin is terminated by the Liaosi uplift and "the crystalline barrier." Another smaller basin of similar strike is located north of the crystalline barrier in northwestern Jehol. Extending further, the Liaosi uplift and the barrier are joined together, forming the northeastern latitudinal elevation of Sunglingshang, which in turns joins the large Liaotung elevation. Some basins extend beyond the boundaries of the platform into the regions of Hercynian structures.

Mesozoic formations are principally confined to basins of the first and second orders but may also occur in flat depressions within elevations. They consist exclusively of volcanic and continental facies. Among them the following rocks can be distinguished: andesite, acidic extrusives, coal-bearing beds, and front-range conglomerates. Lake sediments are less extensive [5, 11, 17, 21].

The andesite formation consists of andesite, trachyandesite, dacite, their tuff and tuff breccia, interbedded with sedimentary conglomerate and clayey and siliceous lake sediments. The frequent occurrence of andesite together with siliceous sediments is possibly caused by the eruption of andesite lavas into the net of river channels, which consequently turned into a chain of lakes, and the lavas themselves became the source of silica of the lake sediments.

Andesites make up the Triassic extrusive complex, in places up to 3 kilometers thick, and the thinner Lower Cretaceous complex; they also occur within other parts of the Mesozoic section.

The acidic extrusive formation consists of liparite, trachyte, variegated acidic glass, and tuffs interbedded with sandy clay sediments. These rocks occur within the Upper Cretaceous where their layers are up to 100 meters thick.

The front range formation consists largely of conglomerate, in places up to one kilometer thick, interbedded with sandstone and argillite. The front range conglomerate corresponds to the periods of most intensive elevation of uplifts and subsidence of basins.

The coal-bearing formation consists of sandy clay, sandstone, siltstone, and argillite with a few enclosed beds of fine-pebbled conglomerate, coal beds and shale. Besides, there commonly occur andesite blankets and their tuffs, bentonite, derived from decomposed andesite or volcanic ash. They generally form easily recognizable and traceable thin layers within coal beds and can be used for the correlation of coal beds.

The typical coal-bearing formation consists of a complex, deposited within intermontane basins that include lake, fluvial, swamp, and volcanic facies. The lake facies sometimes contain bituminous shale. The coal-bearing formation occurs most typically in Middle and Upper Jurassic and Lower Cretaceous sections. Lake sediments occur predominantly in the Cretaceous and consist of variegated argillites, "paper shales," frequently with remnants of fish and insects, marl with inclusions of fresh-water limestone, bituminous shale; they are interbedded with andesite lava. The Mesozoic sediments are as much as 7 kilometers thick in some basins. In flat structural basins within the platform they overlie the eroded surface of older rocks. Barely noticeable angular unconformities can be seen in a few places and seem to be caused by an inclined subsidence of the blocks. However, the sharp change of facies and of the physical and geographic conditions and of the tectonic circumstances suggest that the Mesozoic sequence on the northeastern China platform is an independent structural unit. These facts raise the question of whether or not the existence of a special kind of unconformity is reasonable in places where unconformity marks the contact between the platform sediments and those deposited when the platform began to disintegrate.

The characteristic features of this kind of unconformity are: 1) spotty distribution of overlying sediments while the underlying rocks extend regionally; 2) variegated composition and thickness of the sediments that occupy basins of the first and second orders and the gentle depressions within elevations; and 3) erosional-tectonic contact between the sediments and the older formations of the uplifts.

Intrusive magmatism was especially ex-
nsive during the period of rejuvenation of
e platform. The oldest igneous bodies occur
the form of small granitic intrusives that
ıt the Permian beds and are overlain by
rassic sediments. The age of the granite
believed to be Triassic [21]. During an
termediate magmatic phase of the Early
retaceous, porphyry and dolerite dikes re-
ted to andesite were emplaced. And fin-
ly, during the late magmatic phase, Upper
retaceous, quartz-porphyries and rhyolite
truded and small granitoid intrusives were
rmed, genetically related to liparite and
achyte extrusives of acidic compositions.
ıe magmatic activity accompanied the for-
ation of Mesozoic folds, particularly those
rmed in the Lower Cretaceous beds be-
een Early and Late Cretaceous time, and
the Late Cretaceous. The emplacement of
riassic intrusions and outflow of extrusives
parently coincided with faulting. The Mid-
e Cretaceous tectonic phase was the most
gnificant one in the formation of compli-
ted Mesozoic structures. Steep, generally
ymmetric, or even overturned folds were
rmed in the basins where clay and coal
ds reveal traces of solid flow, such as
ickening of beds at the crest of the folds
d attenuation, in places even complete
sappearance, of the plastic beds in the
nbs. The close folds, especially those at
e margins of basins, are combined with
rike faults and are cut by numerous re-
rse faults, and normal faults. The folds
e several hundred meters wide. The ge-
ticlines are constituted of broad linear
lds and brachyfolds several kilometers
ng. Along the zones where basins and
evations join together, scaled structures
e abundant. Coal deposits in places dem-
strate far advanced carbonization. For
ample, Lower Cretaceous coal in Wafan-
ın is turned into semi-anthracite and is
ked near the contact of small basic in-
ısions.

The above facts concerning the facies
d thickness of Mesozoic sedimentary and
lcanic rocks, their relation to underlying
cks, type of folding, and magmatic activ-
, and finally, the general course of the
ologic development suggest special geo-
ctonic conditions that were manifested in
e northeastern China platform early in the
esozoic. These conditions were actually of
transitional type, between those of a typ-
al platform and a geosyncline; they charac-
rize a certain stage of evolution of a plat-
rm, the period of rejuvenation.

Detailed discussion of the rejuvenation of
e China platform, and especially of other
atforms, is not the subject of this article.
owever, it must be noted that similar proc-
sses have taken place during various periods
of geologic history, not only within the China platform but also in many others.

As mentioned previously, some Mesozoic basins extend beyond the limits of the platform into the areas of Hercynian structures. For example, one of the saggings, the southern end of which is within the platform, extends due north and, without changing its strike, continues within the Hercynian zone parallel to the boundary of the platform, south of Kirin, where Hercynian fold structures form a bay deep within the platform.

Structural basins and accompanying elevations within the Manchurian zone are especially extensive in the east Manchurian mountainous region. Here the Mesozoic basins are confined to six or seven en echelon strips striking northeast but frequently turning almost latitudinally in the north. As an example we may cite the Mutankiang, Tungning, and Mouling basins, separated by elevations composed of pre-Cambrian and highly-folded Paleozoic strata. The basins within the Manchurian zone resemble those occurring within the Manchurian zone resemble those occurring within the platforms; the similarity is emphasized by nearly identical sedimentary facies. However, they also exhibit differences. For example, the sedimentary stratum in the Manchurian zone is thinner, less than 4 kilometers thick; volcanics are less extensive (thickness of the lower extrusive complex does not exceed 300 meters, but the same complex within the platform has a maximum thickness of 3 kilometers). Finally, folding, faulting, and intrusives in the Manchurian zone differ considerably from those of the platform.

Sedimentary formations on elevations are not folded. Structural basins usually have linear folds whose limbs dip from 5 to 50 degrees, but generally from 10 to 30 degrees. Their crests fluctuate in trend very slightly. The Upper Mesozoic units form brachyfolds.

Normal faults prevail among faults; reverse faults are less abundant. Faults along common limbs of elevations and basins seem to have been formed first. Normal faults, and in places reverse faults cutting fold limbs transverse to their strike, are synchronous with folding. Post-folding faults form two principal systems. For example, in the Jouling basin, the earlier system of faults strikes northeast or nearly meridionally, while the later system strikes northwest to latitudinally.

Intrusive magmatic activity was weak, if laccoliths and sills of unknown age occurring east of Kharbin are disregarded. A few quartz porphyry dikes cutting coal-bearing

Cretaceous rocks in the Shuanyashang basin near the boundary of the Sikhote-Alin geosyncline are examples of Mesozoic intrusions. In some other areas, granites of supposedly Cretaceous age may have been injected along faults separating basins from elevations and formed small dike-like bodies.

The Mesozoic sequence within the Manchurian zone as a whole forms an independent structural unit overlying the folded Paleozoic beds and in places the pre-Cambrian strata in sharp angular unconformity. The Mesozoic sequence is separated from the older rocks by a thick weathered crust, apparently formed during the Triassic when the fold zone was a land mass resulting from a general uplift.

In the northern part of the Manchurian Plains, flat-lying Cretaceous sediments a few hundred meters thick, deposited in lakes and swamps, are supposedly underlain by a crystalline basement. They are also present along the southern branch of the zone where no folding took place after the final phase of Hercynian tectonism. As a whole they form a broad and very gentle syncline, the limbs of which are slightly affected by drag-folding at marginal faults.

The folding of the syncline was apparently very slow except in the neighborhood of the Great and Malyy Khingan and the East Manchurian mountains, where large fault planes of northeasterly strike were invaded by quartz porphyry and rhyolite dikes, and also by andesites in the west. Volcanism was more intense along the western margin of the syncline, where subsidence was apparently more rapid; this can be assumed because of the fact that the usual Mesozoic sediments of the Manchurian Plains are not exposed here. In the southern part of the plains, the Mesozoic facies and their bedding characteristics are the same as in the north. A stable Manchurian shield preserved since the time of rejuvenation of the platform underlies this part of the basin, in part of the platform. This shield is surrounded on the east and northeast by the Hercynian structures of eastern Manchuria and on the south by the elevation of Sunglingshang, formed at the expense of the rejuvenated China platform. The crystalline rocks of the shield crop out within the Sungliao horst (divide of the Sungari and Liao-Ho Rivers). Perhaps the stabilizing effect of the old shield pieces, between which the southern branch of the Manchurian zone of Hercynian structures is located, was the reason that this zone was no longer mobile in the Mesozoic.

The Mongol-Okhotsk Belt proper developed quite differently in the Mesozoic. The Permian geosynclinal depression of the Eastern Transbaikal region was joined to this belt, stabilized since the early Paleozoic, and since the Triassic the entire area has had a number of large elongated zones of subsidence. The disposition of these basins and their development were determined by the preceding structural forms [2, 12].

Some of the basins were of geosynclinal type, such as the Jurassic basin of the Eastern Transbaikal region, filled in with thick marine sediments of Jurassic age, intensely folded, and host to a number of magmatic intrusions. This basin is called a "residual geosyncline" by V.N. Kozerenko [2]. The Bureya basin is of similar type. Both basins are superimposed structures. At the present time, many geologists accept the concept that the Mesozoic basins of the Mongol-Okhotsk Belt have been superimposed upon the Paleozoic fold structures since the end of the geosynclinal evolution of the area; they are of secondary origin.

The large east Mongolian-south Transbaikal Barga basin perhaps was joined to the "residual geosyncline" of the East Transbaikal region and occupied the western slope of the Great Khingan Range. Here the Middle Jurassic section consists of andesite, trachyte, and liparite with lake sediments, well dated by a fossil flora, and interbedded with bituminous shale. Because of the extrusives, the bitumen contained in these sediments migrated and formed asphaltite in andesite and rhyolite and local oil occurrences (Chalainor) or lignite. Small intrusions of porphyries and granitoids were also reportedly emplaced in this region synchronously with the extrusives.

The Jurassic sediments form linear folds whose limbs dip 25 to 35 degrees or less.

The Lower Cretaceous (?) lignite layers of Chalainor, overlain by sandstone and shale interbedded with bentonite, tuffaceous layers and gypsum, rest on the eroded surface of the folded Jurassic sequence with angular unconformity, forming a gentle syncline whose limbs are dragged at marginal faults.

Thus, in the Barga basin the tectonism was weaker than in the Transbaikal region. The principal Mesozoic tectonic activity took place here in the Upper Jurassic.

In the Sikhote-Alin region, geosynclinal conditions were preserved in the basins east and west of the central core. The western boundary of the region paralleled the edge of the Ussuri-Khankai massif. North of the Samur range, the boundary continued within China but, because of inadequate knowledge of the geology of this territory and the extensive recent sediments within the area of the lowlands at the Middle Amur River, the

oundary cannot be traced exactly.[1] The oundary turns due northeast approximately Khabarovsk and parallels the edge of the adzhal anticlinorium. The further northern xtension of the boundary has not yet been stablished because of the geosynclinal bays hich, in this part of the area, were deep ithin the region of Hercynian structures of e Mongol-Okhotsk Belt; geanticlines com- osed of folded Paleozoic beds separated ese bays.

The Mesozoic tectonic and magmatic tivity extended into the adjacent Siberian atform and other stable areas, such as the evations of Bureya, the Malyy Khingan, and e Ussuri-Khankai massif. This fact points a tremendous extension of the tectonic tivity of this time. It was most likely lated to the tectonism of the Pacific Belt d extended laterally along zones of eakness. The relationship between the tual and residual geosynclines may be nnected with the events that took place in e Pacific Belt. Similarly, the superimposed sin like that of Barga and the basins lo- ted within the rejuvenated zones of plat- rms and those within the Manchurian zone Hercynian folds may be related to events the Pacific Belt.

CONCLUSIONS

After Late Cretaceous tectonism, the gion under discussion became a stabilized atform. The subsidence of depressions ntinued still further through the Cenozoic thin the fold zones formed of real geosyn- nes, or at the expense of the rejuvenated atform, and in the basins of the second e. The elevations continued to rise but s rapidly. The faults formed were largely the Mesozoic and produced drag folds arby. The plateau basalts of Oligocene age e in the west; those in the east are of ocene or Early Quaternary age; both types st likely were extruded along large fault es. Arch-shaped uplifts and the basins mbined with them were formed after the rusion of Oligocene basalt at the Mon- ian boundary, and in the Quaternary riod in the east. The young basalt flows ered up the valleys that had been cut ough the basalt blankets.

The latest stage of the Cenozoic develop- nt is expressed in the form of recent volcanism and of large superimposed basins bounded by faults. Recent tectonic activity formed structures that control the principal features of the contemporary topography, but the tectonism itself followed the Mesozoic, Hercynian, or even older structural patterns.

Mesozoic tectonism was more significant than the others. It is interesting that the time of its occurrence was predetermined by previous events. They took place in the Jurassic period, within the era of develop- ment of early Hercynian structures of the Transbaikal region; in the Cretaceous within the Manchurian zone, and continued through the Cenozoic within the extreme eastern belt of the Sikhote-Alin range.

The disintegration of the China platform seems to have been controlled by the original form of the platform, i.e., its three narrow elongated projections -- western, northern, and southern. The platform as a whole was T-shaped. The narrow projections were surrounded by extremely active geosynclinal belts and therefore they -- and to a certain degree the rest of the platform -- were less stable than large, rounded platforms, in which the rejuvenation, if any, would involve only the margins.

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[1] The investigations of 1957 determined the esence of extensive geosynclinal formations Triassic and Jurassic age west of Ussuri. rlier, they were considered to be Upper leozoic.

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POLEMICAL QUESTIONS CONCERNING LOWER PALEOGENE STRATIGRAPHY IN SOUTHEASTERN CENTRAL ASIA

by

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The author reviews certain polemical questions concerning the boundary between the Bukhara ıd Suzak formations of the Central Asian Paleogene. Their paleontologic characteristics are re- ewed in the light of new data revealing the vertical distribution of index fossils and faunal mplexes, the confinement of index fossils to certain facies, and publications on the subject. ıe sediments of the two formations occur in the Fergana and Tadzhik depressions.

* * * * *

n 1935, O.S. Vyalov [7] suggested a atigraphic classification of Tertiary sedi- nts in the Fergana basin that later was ended into adjacent areas. According to scheme, the marine Paleogene sediments divided into two divisions and eight for- ions: the Sogda division includes the Buk- a and Suzak formations and the Fergana sion includes the Alay, Turkestan, Rish- Isfara, Khanabad, and Sumsara forma- ıs. The classification is presently used by investigators of the Central Asian Paleo- e.[1]

n recent years the Paleogene stratigraphy Central Asia again attracted the attention geologists and paleontologists. Some au- rs discuss general principles of the exist- stratigraphic classification; [23, 24] other ors review particular sections, their sub- sions and correlations [1, 4, 5, 12-15, 18, 21, 22, 27-31, 34, 36, 37, 39].

Of the works on the regional stratigraphy his territory by O.S. Vyalov [16], A.M. ril'yan [21], and S.N. Simakov [34, 35] especially interesting.

O.S. Vyalov summarized a large collective ıal and stratigraphic study of the Central an Paleogene. He correlated Paleogene sections from various parts of Central Asia, and, largely on the basis of the foraminifera studied, gave the first preliminary correlation of the Central Asian stratigraphic section with that of Caucasia and Western Europe.

A.M. Gabril'yan presented a scheme of littrologic cycles of Upper Cretaceous and Paleogene sediments in the Fergana depression based upon both biostratigraphic and lithologic data, and the nature and peculiarities of the tectonics. These cycles permitted A.M. Gabril'yan to disclose discrepancies in the correlation of Lower Paleogene and Upper Cretaceous sediments in southern and central Fergana and to outline new ways of making correlations ([21], p. 71), the applicability of which were confirmed by the author's studies [30]. A.M. Gabril'yan divided the carbonaceous beds of the Alay formation into littrologic cycles and in doing so attempted to correlate various sections and to draw a conclusion according to which these beds in some areas diminished in thickness or even disappeared. Our extensive data on the fossil fauna and sediments of the Alay formation disclose that A.M. Gabril'yan's correlations and conclusions concerning the Alay formation were erroneous [31].

S.N. Simakov [34, 35], on the basis of meager new paleontologic data, attempts to specify the paleontologic differences between the Bukhara and Suzak formations, and to displace the previously recognized boundary between them by O.S. Vyalov, as well as the boundary between the Suzak and Alay formations. He considerably changed the interpretation of the principal Paleogene sections of the Fergana and Alay mountains and correlated Paleogene sections of the Tadzhik and Fergana depressions in a new manner.

These problems are also discussed in one

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[1] Consistent with the stratigraphic terminology sently accepted in the U.S.S.R., the terms gda and Fergana Series" would be more cor- t, and they should be divided not into forma- ıs but layers (see Stratigraphic and Geochronic divisions, State Geological Technical Press, 4; Stratigraphic Classification and Termi- ogy, State Geological Technical Press, 1956, atigraphic Glossary of the U.S.S.R., State ological Technical Press, 1956). Editor's ıark.

Table 1

Correlation of the Bukhara and Suzak Formations of Paleogene Age in the Fergana and Tadzhik Depressions

I. Tadzhik Depression			II. Southern Fergana				
Vyalov 1939, 1945	Simakov	Characteristic of the Section	Horizons according to Kalitsky	Vyalov 1945	Simakov 1952	Osipova 1953	Characteristic of the Section
Al_1	Al_1	Limestones, marls, clays with Turkostrea turkestanensis		Al_1		Al_1	5. Green marls and oysters with Turkostrea turkestanensis, Pholadomya and other forms
Szk				Szk	Al_2	Szk_3	4. Gypsum with red and green marls, locally replaced by clays, 30 m
Lower Eocene	Szk	2 - 4. Clays and marls with Ostrea hemiglobosa, Gryphaea camelus, Cardita ex gr. pectuncularis, Pholadomya and other forms; 150 m	k	Bch	Al_1	Szk_2	3. Limestone and dolomites with Cuneocorbula and other variegated molluscs; replaced by sandstones due south and west; 10 m
					Szk	Szk_1	2. Clays, silts and sands with variegated molluscs; 52 m
Bch		1a. Marls with Gryphaea antiqua and other molluscs; 20 m				Bch	
Paleocene	Bch	1. Limestones dolomites and gypsum, locally with lagoon fauna (Cuneocorbula and others), locally with marine fauna (Gryphaea antiqua, etc.); 100-200 m	i	Dn	Bch		1, A. White gypsum of Goznau; 26 m
Dn Upper Cretaceous	Dn	A. White gypsum with limestone layers.				Dn	

way or another in the works by O.M. Varentsova-Manuylenko [6] and V. T. Balakhmatova [2], prepared long ago and submitted for publication recently without a review in the light of S.N. Simakov's concepts. On the other hand, N.K. Bykova [4, 5] accepts S.N. Simakov's basic stratigraphic conclusions, while L.V. Mironova [28, 29], A.I. Osipova [30, 31], V.I. Solun [36], and N.I. Chernyak [38] disagree with many of his conclusions.

Errors in S.N. Simakov's concept concerning the subdivision and the relationship between the Rishtan formations of the Fergana and Tadzhik depressions are analyzed by V.I. Solun [36] and do not need to be discussed

Table 1 (continued)

Correlation of the Bukhara and Suzak Formations
of Paleogene Age in the Fergana and Tadzhik Depressions

<table>
<tr><th colspan="3">III. Northeastern Fergana</th></tr>
<tr><th>Characteristic of the Section</th><th>Osipova 1953</th><th>Vyalov 1936</th></tr>
<tr><td>5. Green marls and oysters with <u>Turkostrea turkestanensis</u>, <u>Pholadomya</u> and other forms</td><td>Al_1</td><td>Al_1</td></tr>
<tr><td>4. Red clays and marls with gypsum; 28 m</td><td>Szk_3</td><td rowspan="3">Szk</td></tr>
<tr><td>3. Limestones with <u>Ostrea hemiglobosa</u>, <u>Gryphaea errara</u>, etc. 4 m</td><td>Szk_2</td></tr>
<tr><td>2. Clays and silts with variegated molluscs; 10 m</td><td>Szk_1</td></tr>
<tr><td>1. Gypsum with dolomite layers containing <u>Cuneocorbula</u> and other forms; 25 m</td><td>Bch</td><td rowspan="2">Bch</td></tr>
<tr><td>A. Gypsum with dolomite layers</td><td>Dn</td></tr>
</table>

<table>
<tr><th colspan="4">IV. Northern Fergana</th></tr>
<tr><th>Characteristic of the Section</th><th>Osipova 1953</th><th>Vyalov 1953</th><th>Simakov 1953</th></tr>
<tr><td rowspan="2">4 - 5. Red clays sand stones and gravel; 18 m</td><td>Al_1</td><td>Al_1</td><td rowspan="2">Al_2 + Al_1</td></tr>
<tr><td>Szk_3</td><td rowspan="3">Szk</td></tr>
<tr><td>3. Limestones with <u>Ostrea hemiglobosa</u>, <u>Gryphaea errara</u>, etc.; 12 m</td><td>Szk_2</td><td rowspan="2">Szk</td></tr>
<tr><td>2a. Clays with pelecypods and other forms
2. Gravel with <u>Ostrea kalizkyi</u>, <u>Gryphaea camelus</u>, etc.; 6 m</td><td>Szk_1</td></tr>
<tr><td rowspan="2">1. Red clays, sand stones and gravel</td><td>Bch</td><td>Bch</td><td rowspan="2"></td></tr>
<tr><td>Cr_2</td><td>Cr_2</td></tr>
</table>

ere. Even greater contradictions are appar- nt in the Lower Paleogene stratigraphy (Buk- ara, Suzak, and Alay formations). L. V. ironova [29], in her article entitled Some lemical Problems of Stratigraphy of Central sian Lower Paleogene, contributed consider- ly to the knowledge of paleontologic charac- ristics of the Bukhara formation and demonstrated the incorrectness of S. N. Simakov's concepts [35], according to whom the entire faunal group found in the marl unit between the Suzak clay and the carbonate layers of the Bukhara formation were of Suzak age.

However, in describing the sediments and fauna of the Bukhara and Suzak formations of

Fergana, L.V. Mironova herself made a number of errors[1] and thereby criticized S.N. Simakov even in cases where he was right and had adequate facts. A number of critical remarks concerning the new classification of S.N. Simakov appeared in my dissertation [30], in which, however, I was not able to substantiate my objections adequately.

For the sake of clarity, the extremely complicated paleontology of the Bukhara, Suzak, and Alay formations in Fergana and the Tadzhik depression must be reviewed here in the light of the history of faunal studies in these formations, in the course of which more and more new data have determined the composition and confinement of basic faunal complexes to certain facies. These studies have clarified the vertical distribution of index fossils. Also, the columnar sections of the two Lower Paleogene formations, that of Bukhara and Auzak, must be briefly discussed here, since the division and correlation of these formations is still a debated question because of the extreme facies inequality.

COMPOSITION OF THE BUKHARA AND SUZAK FORMATIONS, THEIR PALEONTOLOGIC CHARACTERISTICS AND BOUNDARIES

In the Late Cretaceous and Early Paleogene, sediments were accumulated in the Tadzhik and Fergana depressions that consisted largely of salty lagoon facies, with few, if any, faunal remnants (Table 1, I-III, layer A and 1). Because of this, the boundary between the Cretaceous sequence and the Bukhara formation is still not clear [11]. In the Tadzhik depression, the boundary has been tentatively drawn within a gypsum-carbonate unit, whose composition on both sides of the boundary was about the same [29, 39], while in the Fergana depression different geologists drew this boundary in various levels of the section; in southern Fergana (Table 1, II) it was drawn along the top of the Goznau gypsum bed [12], along its bottom [35], or in its middle part [21, 30]; in southeastern Fergana -- at the base of the gypsum-carbonate unit [8, 35] or in its middle part [21, 30]; in northern Fergana -- at the base of the lower marine unit [21] or slightly below it, or within the continental redbeds [18, 30].

O.S. Vyalov distinguished the Bukhara formation according to the originally-found fauna of the so-called Kaplanbek complex in which Cuneocorbula, Modiola, Cardita, and Cerithium [9] prevail. This faunal complex consists of uniform species but a great variety of individuals, all of which are small. The confinement of this fauna to gypsum-carbonate sediments suggests a salty lagoon environment. O.S. Vyalov recognized that the Kaplanbek fauna occurs in Central Asia extensively, except in the Tadzhik depression, where it is very rare and is found largely in the western and northwestern part of the depression [9, 29].

The second complex of mollusks, called the Karatag complex, is more variegated and consists of large forms, including some species which lived in Paleocene seas of the Volga basin, Transcaucasia, and Crimea [16, 33]. The fauna of the Karatag complex was first found by B.A. Petrushevskiy [33] in the Tadzhik depression, in the marl unit lying between the limestone of the Bukhara formation and the clay of the Suzak formation (Table 1, I, layer 1-a). The boundary between the two formations is usually drawn according to lithologic changes, i.e., at the contact between limestone and clay; the boundary becomes uncertain when limestone and clay are separated by marls that contain the Karatag complex.

B.A. Petrushveskiy describes the distribution of the Karatag fauna as follows: "Marls gradually pass into underlying limestone and a definite boundary between them can hardly be drawn, whereas the transition to the overlying grey clay is gradual but takes place within a short distance. The clays are rich in Ostrea camelus Burac., and contain lesser amounts of Ostrea meiglobosa Rom. and large oysters of the gigantica group (Suzak formation). The Karatag fauna complex is confined to the upper part of the marl. The thickness of the unit is 10 to 12 meters. The lower part does not contain any fauna. The upper part contains hardly recognizable marl nuclei of pelecypods, rarely gastropods, and numerous phosphiritized Gryphaea escheri. Above the

[1]For example, L.V. Mironova still considers the lower unit of marine sediments in northern Fergana to be a part of the Bukhara formation (see Table 1, IV, group of layers, II), although they contain such typical oysters of the Suzak formation as Gryphaea camelus Burac. and Ostrea hemiglobosa Rom., because of which other investigators [18, 30, 35] consider them to be a part of the Suzak formation. The faunal complex ([28], p. 190) found in the overlying clay beds (Tables 1, IV, beds 2a) is considered by all geologists to be of the Suzak formation [5, 6, 16, 30, 35], while L.V. Mironova, without giving any reason, includes it in the faunal group of the Bukhara formation, and in the correlation table of Paleogene sections of the Tadzhik depression and of Fergana ([28], p. 193) she missed the limestone unit with Ostrea hemiglobosa and other forms, which is extensive in northern and northeastern Fergana. Because of these errors, a reader gets a completely wrong impression about the Suzak formation in Fergana -- as if it consisted of gypsum-bearing and red-colored sediments.

ırl, i.e., in clay with Ostrea hemiglobosa, ıs fauna was not found." "The majority of e forms cannot be determined because of eir poor preservation, consequently only e following forms can be mentioned at this ne: Gryphaea escheri var. antiqua Schwetz.[1] ırritella kamyschinensis Netsch., Pholadomya neata Sow., Protocardium[2] cf. semidecus-tum Koen., Cyprina spec. (cf. morrisi w.). Protocardium sp. ind., Pholadomya . ind., and Ostrea sp. ind., occur in hardly cognizable forms." ([33], p. 82).

B.A. Petrushevskiy, impressed by the fact ıt the marl everywhere passes into under-ng limestones gradually, considers the nestones a part "of the Paleogene cycle of dimentation" ([33], p. 83). O.S. Vyalov, for e same reason, included the Karatag fauna the Bukhara formation. However, as recog-zed recently by O.M. Varentsova-Manuy-ıko [6], Vyalov in some cases included the ınsitional unit and its fauna in the Suzak rmation. This fact, as we shall see later, oduced an erroneous concept that the fauna the Karatag unit and that of the Suzak for-ıtion are very similar.

Let us now review the fauna confined to e lower Paleogene beds in Fergana. At the ıe of his monographic work on the fauna of e Bukhara formation, O.S. Vyalov [9] first d only the fauna collected by other persons ım northwestern Fergana available (Table 1, layer 1). Among this fauna he identified e following species of the Kaplanbek com-ex: Corbula (Cuneocorbula) angulata Lam., Triangulata Vial., C. Gorizdroae Vial., asiatica Vial., C. turkestanensis Slodk., ɔdiola cf. jeremeiewi Rom., Cerithium cf. ravshanensis Vial., Potamides (?) roma-vskyi Vial., and also Bulla spe.

Later, during his field studies, O.S. Vya-found fossils of the same Kaplanbek com-ex in southern Fergana (Table 1, II, layer layer "K" of Kalitskiy). We draw the ındary between Cretaceous and Paleogene diments at the base of rocks containing se fossils, between layers 2 and 3 (Table III) in southern Fergana and between layers and 1 (Table 1, III) in northeastern Fer-ıa. The fauna of the Kaplanbek complex s not found in northern Fergana, and O.S. alov believed the lowest marine beds rest ɔn the redbed sequence containing Ostrea izkyi Vial ([8], p. 17) to be a part of the Bukhara formation; later, he also found Ostrea bellovacina Lam. var. trunkleri Boehm and other mollusks in these layers, determined by O.M. Manuylenko to be Nemocardium cf. edwardsi Desh., Cyprina cf. morrisi Sow., Glycimeris aff. vaudini Desh., Pectunculus aff. pseudopulvinatus d'Orb., P. ex gr. poly-morphus Desh., Meretrix cf. Ovalina Desh. (Table 1, IV, layer 2). This group of fossils was included by him [18] in the Karatag com-plex, but now his opinion seems to be wrong.

Later studies and new data altered the concepts on the age of certain layers and on the boundary between the Cretaceous and Paleogene strata in Fergana. For example, having found Ostrea bellovacina Lam. var. trinkleri Boehm in layer 2 of southern Fer-gana, O.S. Vyalov [12] lowered the boundary between the Cretaceous and Paleogene strata and suggested that the boundary be drawn at the top of the Goznau gypsum (Table 1, II, layer 1).

V.T. Balakhmatova also identified the following fossils in layer 2 of southern Fer-gana (Table 1, II): Nemocardium cf. edwardsi Desh., Cyprina morrissis Sow., Glycimeris cf. vaudini Desh., G. currugata Dixon, G. elongata Leym., Cucullaea dorsorotundata Netsch., C. gibbosa Netsch., Arca aff. dulwichiensis Wood, Pectunculus sp., Cardita ex gr. pectuncularis Lam., C. ex gr. multi-costata Lam., C. cf. longa Arkh, Nucula sp, Tellina sp., and Ostrea kalizkyi Vial. She called this group the Sulyukta complex and pointed to the close similarity of this com-plex to that determined earlier by O.M. Manuylenko in northern Fergana (Table 1, IV, layer 2). The first three species of pelecy-pods and Ostrea kalizkyi and O. bellovacina Lam. var. trinkleri Boehm were found in both southern and northern Fergana.

Later, in the lower marine unit in northern Fergana (Table 1, IV, layer 2), R.F. Gekker, A.I. Osipova, and T.N. Bel'skaya found Gryphaea camelus Burac, which is a typical oyster of the Suzak formation in the Tadzhik depression. Because of this form, O.S. Vyalov and the author [18] consider the unit to be a part of the Suzak formation. The same con-clusion concerning the Suzak age of the lower marine unit in northern Fergana was drawn by A.A. Vorob'yev ("Sredazneft" Trust -- Central Asian Oil Trust) and S.N. Simakov, who also found some other forms of the Suzak fauna, such as Ostrea hemiglobosa Rom. and Gryphaea errara Vial. in this marine unit.

The occurrence of Ostrea kalizkyi Vial. and O. bellovacina Lam. var. trinkleri Boehm, together with the typical fossils of the Suzak formation permitted S.N. Simakov to clarify the stratigraphic position of these two species.

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[1] O.S. Vyalov [17], in his monograph, called s form Gryphaea antiqua Schwetz.

[2] O.M. Varentsova-Manuylenko [6] and V.T. lakhmatova [2] include this species in the ıus of Nemocardium.

Earlier, O. kalizkyi, known only in the lower marine unit of northern Fergana, was considered to be confined to the Bukhara formation, while O. bellovacina Lam. var. trinkleri was found together with the former in the Suzak formation [10]; now both species appear to be confined only to the Suzak formation.

Since the fauna found in the terrigenous sediments of southern Fergana are similar to those known in the lower marine unit of northern Fergana, S.N. Simakov [34, 35] drew a correct conclusion, i.e., that the terrigenous sediments of southern Fergana, overlying the Goznau gypsum, earlier considered to be a part of the Bukhara formation or Cretaceous beds, are actually a part of the Suzak formation (Table 1, II, layer 2).

This conclusion was also confirmed by N.K. Bykova [5], who studied foraminifera, and by our data [30]. For example, in the terrigenous sediments of this unit (Table 1, II-IV, layers 2 and 2a), R.F. Gekker, A.I. Osipova, and T.N. Belskaya found the same fossils in 17 places, of which five are in southern Fergana (Kalacha-Mazar, Isfara, Shurab, Buzhum, Kamysh-Bashi), two in southwestern Fergana (Ambargaz, Sulyukta), one in northwestern Fergana (Shaydan Ashtskiy), six in northern Fergana (Varzyk, Aylyama, Surkhi, Karaunkur, Ak-Say, Naryn), and three in northeastern Fergana (Arslanbob, Kara-Art, Changyr-Tash). Besides Ostrea kalizyki Vial., O. Bellovacina Lam. var. trinkleri Boehm, Gryphaea camelus Burac, poorly preserved remnantes of pelecypods and gastropods were also found here, among which Ye. V. Liverovskaya could identify Cyprina morrisi Sow., Cardita ex gr. pectuncularis Lam., C. ex gr. multicostata Lam., Cardium ex gr. edwardsi (Desh)., Panopaea elongata Leym., P. aff. corrugata Dixon, Solecurtus subsolenoides (Man.), Meretrix aff. montensis Cossm., M. cf. ovalina Desh., Modiola elegans Sow., Corbula karaunkurica Liwer., Potamides romanovskiy Vial. var. The following genera were also included: Cucullaea, Arca, Pectunculus, Nucula, Perna, Lucina, Crassatella, Isocardia, Natica, and Fusus.

The correlation of the columnar sections from various parts of the Fergana depression was greatly aided by the discovery of the Sulyukta faunal complex in northeastern Fergana, in a silt-clay unit between the lagoon sediments of the typical Bukhara formation and the linestone yielding typical oysters of the Suzak formation (Table 1, III, layer II). Until recently, the fossils of the Sulyukta complex in this region were believed absent ([2], p. 173; [28], p. 190). Tracing the clay-silt unit, which contains variegated mollusks of the Sulyukta complex (Table 1, II-IV, layer 2), from the southern part of the Fergana depression through the northeastern to northern districts of the depression permits accurate correlation of both the overlying and the underlying units; limestone with Ostrea hemiglobosa and Gryphaea errara, which occur in northeastern and northern Fergana (Table 1, III, IV, layer 3), were found to correspond to the limestone and dolomite of southern Fergana in which various mollusks, locally mollusks of the Kaplanbek complex layer "k" of Kalitskiy, (Table 1, II, layer 3) were found, while the unit of interbedded gypsum and dolomite containing Cuneocorbula in northeastern Fergana (Table 1, III, layer 1) corresponds to the Goznau gypsum of southern Fergana.

This correlation of the Suzak formation of southern, northern, and northeastern Fergana discloses that the concept according to which the Suzak formation was deposited in different parts of the basin under different conditions is a mistake; it was believed that in the north the marine sedimentation started with terrigenous material, succeeded by carbonates, and both became overlain by continental redbeds, while in the south the Suzak formation consisted exclusively of gypsum-bearing lagoon sediments [16]. Now the three lithologically different units, distinguished earlier by O.S. Vyalov (16, p. 125) in the Suzak formation of northern Fergana, have analogues in the southern part of the depression. Table 1 shows that all the principal sections consist of three units, of which the lower (Szk_1) is composed of clastic sediments containing various marine mollusks and, according to N.K. Bykova [5], foraminifera largely consisting of sandy forms; the middle (Szk_2) is represented by various marine sediments, in the northeast largely by limestone, and in the south and west by limestone, dolomite, and sandy rocks; and the upper (Szk_3) in the south and northeast is composed of variegated gypsum-bearing sediments of salty lagoons, and in the north of continental redbeds.

Like the lower, the middle unit contains various mollusks and foraminifera, largely of the Miliolides family [5]. In the upper unit no fossils were discovered until recently, but now in two places in the western part of the depression, near the top of the lagoon sediments, lens-shaped limestone with Meretrix and Turritella remnants were found. These two marine fossils indicate that the Fergana lagoon was connected with an open Paleogene sea [30]. It should be noted that until 1951, A.M. Garbil'yan doubted the correctness of the correlations between the carbonate sediments of the Suzak formation of northern Fergana with the gypsum-bearing sediments of southern Fergana and expressed the opinion that the carbonate unit of the Suzak formation of the south (layer "k"), and

e overlying lagoon sediments with the red avel of northern Fergana ([21], p. 71) are rrelative. The facts discussed above con- rm A.M. Gabril'yan's concept but contradict at of S.N. Simakov (35), according to whom e "k" layer of the south lies at the base of e Alay formation and must be correlated th the red sediments of the north (Table 1, , layers 4-5).

What is new in our concept concerning the khara formation in Fergana and its bound- ies, on the basis of the new correlations?

Since the Suzak age of the sandy-clay sedi- ents is an established fact, the underlying znau gypsum of southern Fergana and the ssiliferous, sulfate-carbonate sediments of e Bukhara formation of northeastern Fergana ust be equivalent lagoon deposits. The same nclusion was drawn by A.M. Gabril'yan [21] the basis of stratigraphic cycles and later S.N. Simakov [34]. Consequently, the undary between the Cretaceous and Paleo- ne must differ from that drawn by O.S. alov [16] at the base of the sulfate-carbon- e sequence in northeastern Fergana and at top of the same sequence in southern rgana (Table 1).

The Cretaceous-Paleogene contact has been awn differently by different investigators. N. Simakov, without presenting evidence, nsiders the entire Goznau gypsum and other nchronous layers to be part of the Bukhara mation ([35], p. 211; [39], p. 21). A.M. bril'yan [21] concludes that only the fossil- rous upper part of the carbonate-gypsum quence of northeastern Fergana should be ought of as part of the Bukhara formation, was thought about southeastern Fergana aukat Basin) by O.S. Vyalov; the lower part the formation is, according to Vyalov, of nish age. This concept seems to me to be ost acceptable [30]. It is consistent with the own data on the Tadzhik depression, whose mplete sections demonstrate that the top of Paleogene form a single gypsum-carbonate quence. In the sections where the lagoon ction does not contain fossils (for example, Goznau gypsum), the Upper Cretaceous d Paleogene parts of the sequence could not s far be divided and, consequently, the undary is usually drawn in the middle of sequence.

A.M. Gabril'yan assumes that the litho- ically similar beds of the Bukhara and nish formations in southern Fergana are parated by a disconformity, although in rthern Fergana he found an angular uncon- mity between them [21]. This assumption uld not be confirmed by the data available me [30].

Finally, L.V. Mironova [28], following an early concept of O.S. Vyalov, according to whom the lower marine unit of northern Fergana is a part of the Bukhara formation, correlates this unit, as previously, with the terrigenous strata of southern Fergana (Table 1, II, layer 2) and with the gypsum-dolomite sequence of northeastern Fergana (Table 1, III, layer 1). This correlation, which is close to the earlier point of view of A.M. Gabril'yan and the present author, produces an erroneous impression that the sediments of Bukhara age vary widely in facies which show an unusual lateral distribution. In these facies the clastic and clastic-carbonate sediments with a diverse marine fauna occur in the north, at the margins of the basin, while lagoon sediments occupy the central part of the basin ([20], p. 70, Fig. 3). Now, new correlations produce a facies map according to which the entire area of the Fergana basin is an area of lagoon sediments of the Bukhara formation except for the northern margin occupied by continental redbeds.

Thus, the new data produced by S.N. Simakov and others, according to whom the lower unit of the northern Fergana section is a part of the Suzak formation and synchronous with the terrigenous sequence of southern Fergana, greatly helped us correlate correctly the sediments of the Bukhara and Suzak formations that occupy parts of the widely-spaced sections of the Fergana depression.

This new correlation discloses another important fact, viz., the Kaplanbek faunal complex occurs in Fergana in two units of lower Paleogene age: a) in carbonate layers within the lagoon sediments of the Bukhara formation, and b) in layer "k" of southern Fergana resting upon the fossiliferous sediments of the Suzak formation, and can be correlated with the Suzak limestone of northern and northeastern Fergana.

In evaluating the distribution of the Kaplanbek and Karatag faunal complexes in the Tadzhik and Fergana depressions in the first chapter of his publication [35], S.N. Simakov draws the conclusion that the two faunal complexes are not confined to a single stratigraphic unit, as was believed until recently, but to two different units: the Kaplanbek complex to a lower (Bukhara formation) and the Karatag complex to a higher (Suzak formation) unit. S.N. Simakov did not mention the fact that the Kaplanbek faunal complex, on the basis of which O.S. Vyalov correlated the sections of southern and northeastern Fergana, occurs in southern Fergana above the Suzak formation. Only in the chapter in which he discusses the Suzak and Alay formations ([35], pp. 209-210) does S.N. Simakov mention the presence of Corbula (Cuneocorbula) angulata Lam., C. asiatica Vial., Modiola jeremejewi Rom., Potamides (?)

romanowsky Vial. in the "k" layer and conventionally recognize this fauna to be a guide to the Bukhara formation. However, he considers this unit to be a part of the Alay formation and writes: ". . . in this case, we must admit an error in our earlier concepts and assume that the above four species occur within much broader stratigraphic intervals, from the Bukhara to the Alay formations; this is similar to the distribution of Corbula angulata Lam. in the Paris basin, where, according to O.S. Vyalov, this species occurs in many units from the Thanetian to the Bartonian formations." ([35], p. 210).

This assumption contradicts S.N. Simakov's own data presented at the beginning of his article, where he states that the Kaplanbek complex (and only it) is a typical faunal group of the Bukhara formation.

Furthermore, on the basis of the supposedly established confinement of the Karatag complex to a higher stratigraphic unit than the Kaplanbek complex, S.N. Simakov writes: ". . . in northern Fergana this marl unit unquestionably is a part of the Suzak formation because of the recently-discovered Ostrea hemiglobosa Rom. and Gryphaea errara Vial in this complex. In the Tadzhik depression, this unit must also be considered a part of the Suzak formation. Here its fauna is completely foreign to the Kaplanbek complex, but it is very close to the Suzak complex; almost all the species found within the marl unit occur in the Suzak formation as identical or similar forms. In the Suzak formation, O.S. Vyalov ([9], p. 29) found, besides other species: Gryphaea antiqua (Schwetz.) Protocardium edwardsi Desh., Pr. cf. semidecussatum Koen., Pholadomya cuneata Sow. var. vialovi Man.; and other authors have also found Ampullina cf. semipatula Desh., Cucullaea crassatina Lam., Cyprina morrisi Sow. (identified by I.A. Korobkova).

The above facts permit us to include all the species of the Karatag complex in the well-known Suzak complex and go back to the original concept of O.S. Vyalov [5] concerning the Bukhara formation. It must be stated, thereby, that exclusion of the Karatag complex from the Bukhara formation once again emphasizes the loss of the paleontologic differences between the formations of the Sogda division in terms of both the species contained and the prevalence of endemic forms in the Bukhara formation, while a large number of Crimean and Volga species appear in the Suzak formation. This difference probably results from the lack of connections with an open sea during Bukhara time and their reestablishment during the Suzak time ([35], p. 203)."

The similarity of the Karatag complex with the fauna of the Suzak formation will be reviewed later, but now we will review only the paleontologic differences between the Bukhara and Suzak formations, as restored by S.N. Simakov.

S.N. Simakov's suggestion to return to "the original concept about the Bukhara formation" means that he believes it possible to characterize the Bukhara formation by the Kaplanbek faunal complex alone. However, a few pages later, interpreting the presence of this complex in layer "k" of southern Fergana (above the sediments with the fauna of the Suzak formation), he assumes that some species of this complex are distributed from the Bukhara to the Alay formations, inclusively. Exactly what is the sharp paleontologic difference between the Bukhara and Suzak formations about which S.N. Simakov writes]

S.N. Simakov's concepts of the fauna of the Bukhara and Suzak formation are now accepted by some paleontologists who studied the fauna of the Suzak formation. For example, V.T. Balakhmatova [2], N.K. Bykova [5], and O.M. Varentsova-Manuylenko [6], like Simakov, disregard some previously-known facts that contradict S.N. Simakov's conclusions and data.

For example, as early as 1939, O.S. Vyalov, studying the sediments of the Tadzhik depression, found poorly preserved shells of numerous pelecypods and gastropods in the carbonate layers of the Bukhara formation, and among them identified large Cyprina (?) sp. Cardium (?). Ostrea sp. and serpula, bryozoa and echinoidea ([11], pp. 7 and 13). In the upper marl layer, which is the transitional unit between the Bukhara and Suzak formations (Aruk-Tau, layer 4; Tutkaul, layer 1), Pholadomya sp., Ph. cuneata Sow. var. vialovi Man., Ph. konincki Nyst var., Cyprina (?) sp., Cardium sp., Panopaea sp., Turritella sp., Cerithium sp., Gryphaea antiqua (Schwetz.), and a sea urchin ([11], pp. 8, 13, and 18) were also found.

Even excluding the latter forms found in layers of questionable age, we see that the fossils of the carbonate layers, considered by S.N. Simakov to be a part of the Bukhara formation, are not typical representatives of the Kaplanbek complex. The presence of echinoidea and bryozoa indicate that the conditions in the Tadzhik basin, at least during certain parts of Bukhara time, were close to those of an open sea.

This was confirmed by V.B. Tatarskiy, who found, in carbonate laters of the formation within the Tadzhik depression, a unit containing remnants of echinoderms and other

una [37], and L.V. Mironova [28, 29], who und an extensively distributed and diverse una of mollusks not only in the upper tran- tional marls but also in the lower, in car- nate layers of the Bukhara formation.[1]

All the facts, both published and recently scovered ones, suggest a change of condi- ons during which the thick carbonate-gypsum quence of the Bukhara formation was accum- ated in the Tadzhik basin. The conditions ere close to those of lagoons when the Kap- nbek faunal complex inhabited the sea (e.g., ineocorbula, etc.) and normal marine con- tions prevailed because echinoderms and rms of the Karatag faunal complex occupied e basin.

Thus, S.N. Simakov's conclusion that the ratag faunal complex should be excluded om the faunal groups of the Bukhara forma- on and considered a typical group only of e Suzak formation is completely baseless.

Let us now discuss the stratigraphic posi- on of the transitional marl unit of the Tad- ik depression, within which the Karatag unal complex was first recognized (Table 1, layer 1a).

As mentioned previously, S.N. Simakov serts that the faunal makeup of the marl it is very close to that of the fauna known om the Suzak formation. In confirmation of is, he cites three forms found by him in e Suzak layers within the Tadzhik depression d some species found earlier by O.S. Vya- v. He thereby draws attention only to simi- r species and does not mention many forms und only in the Suzak formation, viz., its ide fossils. Among these, the oysters, are rticularly well distributed: Ostrea hemi- obosa Rom., Gryphaea camelus Burac., . smirnovi Rom., as well as various ctinids, such as Chlamys abominosa Korobk., l. Suzakiensis Korobk., Chl. estimiensis orobk., Chl. edecimata Korobk., Camp- nectes khatschiljorensis Korobk., Pseuda- ussium corneum Sow. were identified. Also, erebratula sp. is thus far known only from e Suzak formation. This is of special terest because no brachyopods were found other units of the Central Asian Paleogene.

Let us also mention that in selecting some ecies from a complete list presented by S. Vyalov, S.N. Simakov left out the fact at in two sections, O.S. Vyalov included e transitional marl unit in the Suzak forma- tion and because of this the paleontologic difference between the two formations became obscured. For example, one of the guide oysters, Gryphaea antiqua Schwetz, was believed to occur at the top of the Bukhara and at the base of the Suzak formations. However, a correct correlation of the marl unit (see correlation of the Arak-Tau, Tut- kaul, and Khochil'or sections by O.M. Varentsova-Manuylenko, [6] discloses that Gryphaea antiqua does not occur above the transitional unit, whose thickness is 10 to 20 meters. This is completely consistent with the data presented by B.A. Petrushevskiy concerning the distribution of Gryphaea antiqua and is confirmed by our field studies in the Tadzhik depression in 1952, and with the data re-examined in the extensive material collected by geologists of the TERMEZNEFT Trust (Termez Oil Trust) [30]. Besides, K.B. Babkov found Gryphaea antiqua in a number of places in the Tadzhik depression, where it occurs below the transitional unit, within the carbonate layers of the Bukhara formation.

This fact permits us to consider Gryphaea antiqua (Schwetz.) a form typical of the Buk- hara formation. Its distribution along the section must be taken into account if the top of the Bukhara formation is to be determined. A complex of other mollusks found together with Gryphaea antiqua in the transitional unit is also of the Bukhara formation. Specifically, this group of mollusks should be called the Karatag complex and it should not include, contrary to recent concepts [16, 28, 34, 35], the younger fauna of the Suzak formation of Fergana, despite its similar origin and en- vironment, for no Gryphaea antiqua (Schwetz) occurs among them although there are a great number of Ostrea hemiglobosa Rom., O. bellovacina lam. var. trinkleri Boehm, Ostrea kalizkyi Vial., Gryphaea errara Vial., and Gr. camelus Burac.[2]

The absence of Gryphaea antiqua in the Bukhara formation of Fergana can be ex- plained by facies differences. In the salty lagoons of Fergana, only a suppressed fauna of the Kaplanbek complex could live, and even this fauna migrated largely from the eastern part of the basin adjacent to Alay Strait, which was connected with the Tadzhik Sea [30, 32].

The similarity of the mollusks found in the Suzak formation and in the transitional unit cannot be a basis for regarding the transitional unit in the Tadzhik depression as a part of the Suzak formation, for some of the same species also occur in underlying carbonate layers of the Bukhara formation [29].

Cyprina morrisi Sow. and Menocardium wardsi Sow., among others, were found; ese forms are considered by other authors be guide fossils of the Suzak formation.

[2]The species of this association found in south- ern Fergana are known as the Sulyukta complex.

Most likely, these are forms that have lived both during Bukhara and Suzak time. Among them Cyprina morrisi Sow., Nemocardium edwardsi Desh. and other forms were found in the Suzak formation, in the marl unit of the Tadzhik depression, along with the Karatag fauna and in underlying carbonate layers of the Bukhara formation [2, 6, 28].

As mentioned previously, these forms also inhabited the European part of the Paleogene Sea. According to V.T. Balakhmatova [2] and O.M. Varentsova-Manuylenko [6], they occur in both Paleocene and Eocene sediments of western Europe and consequently are species that survived over long periods of time. They inhabited the Central Asian Basin when the conditions in the basin were close to normal marine. During Bukhara time, the conditions favorable for a diverse fauna, including those discussed here, existed in central and southern parts of the Tadzhik Sea, but later, during Suzak time, the same conditions obtained in the entire area of the basin. In the Bay of Fergana, similar conditions prevailed only at the beginning of and during middle Suzak time, when various mollusks were indigenous to the bay. Among them, species of the Pectunculus genus, according to Ye. V. Liverovskaya [25], indicate the saltiness, which was close to that of the ocean.

Thus the normal marine character of the fauna and presence of the same forms known from the European part of the Paleogene Sea make the fossil fauna of the Suzak formation similar to that of the fossil marine fauna found in the Bukhara formation of the Tadzhik depression (the Karatag complex), but as the data indicate, faunal complexes of the two formations, especially the typical species of oysters, differ considerably.

It should be noted that the other sedimentary formations of the Central Asian Paleogene (for example, the Alay and Turkestan formation) also contain a similar microfauna and isomyarian mollusks [3, 25, 26], but the formations can be clearly distinguished because the oysters in each formation are represented by different species or even different genera.

It is noteworthy that O.S. Vyalov [16], in summarizing his studies on the Central Asian Paleogene fauna, emphasized the significance of oysters as local guide forms and stated that they must be considered as the primary guide forms rather than other mollusks or the microfauna. This conclusion was fully confirmed by our several years of study in the Fergana and Tadzhik depressions, in the sense that the oyster distribution must be observed most carefully.

Some recent articles suggest (however, without adequate background data) the fact th certain species of oysters are not always co fined to certain formations within the Middle Asian Paleogene, but occur in two or three formations [29]. We have had several occasions to become convinced that similar state ments are based on confusion and usually result from inaccurate determinations by inadequately experienced paleontologists. Recent studies contributed only a few correc tions to the stratigraphic distribution of oysters established by O.S. Vyalov. Consequently, the corrections made the stratigrap ic distribution of some oyster forms narrow For example, it was believed that Ostrea bellovacina Lam. var. Trinkleri Boehm and Gryphaea antiqua (Schwerz.) occur in both the Bukhara and Suzak formations, but now it is clear that the former is typical of the Suzak formation [35] and the latter of the Bukhara formation [30].[1]

Correlation and differences in the faunal complexes of the Bukhara and Suzak formations have not yet been made completely clear. The recent dissertation by L.V. Mir nova [28], entitled Stratigraphy and Fossil Mollusks of the Bukhara Formation in Cent Asia, does not close the gap in our knowledge, because the author does not compare the fauna studied by her with that of the Suzak formation but describes mollusks fro various places and various units of the Low Paleogene together, including those from th basal marine unit of northern Fergana, whi is now considered by all other authors [2, 6, 18, 30, 34] to be a part of the Suzak formation.

A comparative study of the microfauna o these two formations has not yet been carri out. N.K. Bykova [4], who studied the micr fauna of the Suzak formation and that of th transitional unit within the Tadzhik depressi states that the general characteristics of th foraminifera in this unit are similar to the foraminifera of the Suzak formation that inhabited a basin of normal saltiness but diffe essentially from the peculiar microfauna of the Bukhara formation (miliolid complex) tha lived in a basin whose saltiness was quite different from that of a normal sea. Becaus of this fact, N.K. Bykova believes that the transitional unit should be considered a par of the Suzak formation. This conclusion is not a proven fact, for the foraminiferal com plex of the Bukhara formation may differ

[1]In this connection, the boundaries between the Bukhara and Suzak formations in Kashgara Province and other districts should be defined more closely because Gryphaea antiqua occur there, as in the Tadzhik depression, in the Bukhara formation and at the base of the Suzal formation.

om that of the transitional unit because of a fferent environment. This may, as we know, the case even in strictly synchronous sediments. Consequently, the data on the microuna is not yet a factor that could decide the clusion of the transitional unit in one or other formation. The most convincing data obably will be obtained after the study of raminiferal complexes within the Tadzhik sin, where, at certain periods of Bukhara ne, the environment was close to that of rmal seas and the fauna was plentiful (e.g., hinoidea, oysters, various mollusks).

Thus the oysters are still the most relile fossils for delineating the Bukhara and zak formations; on the basis of their disbution, the transitional unit within the dzhik depression, in which Gryphaea iqua (Schwetz.) was found, must be conlered a part of the Bukhara formation.

CONCLUSIONS

A re-examination of the Paleogene strati- phy in the Fergana and Tadzhik depresns, initiated by S.N. Simakov, led to inement of the stratigraphic position of terrigenous sequence of the Sogda division hin the Fergana Basin (Table 1, layer 2), l contributed to a correct correlation of layers of the Bukhara and Suzak formans of various parts of the Fergana depresn. However, S.N. Simakov did not have equate observations of his own and did not the data of other authors to the full ext needed to solve an even more important blem concerning the boundaries and the nal characteristics of the Bukhara, Suzak, Alay formations. He did not correlate sediments of the Alay formation in the rgana and Tadzhik depressions. Consently, he came to erroneous conclusions.

An analysis of the available data, underen in order to disclose the dependence of distribution and the changes in faunal nplexes on the changing factors of environnt, did not confirm S.N. Simakov's consion that the Bukhara formation consists lusively of lagoon sediments. Simakov tended that this lagoon facies contained an emic fauna of the Kaplanbek complex, le the Suzak formation is characterized the marine Karatag faunal complex, including those forms that inhabited the European t of the Paleogene Basin.

n reality, some forms of the European a also lived in the Central Asian Basin Bukhara time, but they were restricted to ricts of nearly normal marine conditions.

Between Bukhara and Suzak time, the environment did not change instantly. Consequently, some species (including those invaders from the European part of the Paleogene Sea, such as Cyprina morrisi Sow., Menocardium edwardsi Desh., and other forms that inhabited the Tadzhik Sea during Bukhara time) continued to live in the Tadzhik and Fergana basins during Suzak time. Because of these identical species and similar ecologic characteristics (normal marine fauna), the marine (Karatag) complex of the Bukhara formation in the Tadzhik depression resembles the mollusk complex of the Suzak formation in the Fergana and Tadzhik depression.

The data presented in this article reveals that the complexes of marine mollusks of the Bukhara and Suzak formations differ from each other considerably. The differences are especially clear in the case of oysters. Among the marine fauna of the Bukhara formation (Karatag complex), Gryphaea antiqua (Schwetz.) is very common. It also occurs in Paleocene sediments of Transcaucasia and the Crimea. Among the mollusks of the Suzak formation, Ostrea hemiglobosa Rom., Gryphaea camelus Burac., Ostrea bellovacina Lam. var. trinkleri Boehm, and other forms occur in great numbers.

The mollusks of the Kaplanbek complex, that lived in waters of high salt content, largely inhabited lagoons during Bukhara time but also survived through Suzak time.

Table 1 represents a new correlation of the sediments of the Bukhara and Suzak formations recognized in the three principal sections of the Fergana and Tadzhik depressions and a detailed division of the sediments of the Suzak formation within the Fergana basin.

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GEOLOGICAL-GEOPHYSICAL SECTION OF THE PACIFIC CONGRESS, NINTH SESSION, BANGKOK, THAILAND

by

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[The Soviet delegation at the Ninth Session :he Pacific Congress in Bangkok in Novem- 1957, was composed of D.I. Shcherba- , member of the Academy of Sciences of U.S.S.R. (Head of the delegation); P.A. /seyev, Doctor of Biology; A.G. Kolesni- , Doctor of Physics and Mathematics; V. Karus, Candidate of Physics and hematics; P.V. Ushakov, Doctor of ogy; Ye. F. Guryanov, Doctor of Biology; . Mamrykin, Candidate of Economics; A.V. Krivopalov (Secretary).

[The sessions of the Pacific Congress are ılly convened by the permanent Pacific ociation, the scientific council of which udes representatives of 14 countries: tralia, Canada, Taiwan, France, Japan, nam, the Netherlands, New Zealand, the ippines, Thailand, the United Kingdom, U.S.A. and Hawaii, and Indonesia. The sions are devoted to "developing and ngthening collaboration in the solution of ntific problems that will affect the pros- ty of the peoples in the Pacific region."

'he ceremonial opening of the Ninth sion took place on November 18, in the torium of the Commission for Economic aboration of Far Eastern Countries. The ıe Minister of Thailand delivered the coming address in Siamese; he empha- d the international character of science the significance of the development of rnational communication. After him, the idents of the past and present sessions ıe Congress delivered their speeches.

f the total 800 delegates at the Ninth ion of the Congress, 467 were from 28 tries directly interested in the problems ıe Pacific Ocean. The U.S.A., with 196 gates, had the greatest representation; Philippines had 35 delegates, Japan 31, Federal Republic of Malay 17, Australia England 12, France 10, and so on. y delegates came from Hong Kong, apore, and other dependent countries and nies. The Thailand delegation (300) was active and presented 90 reports.

After the opening ceremonies, 18 sections started their work on the following subjects: geology and geophysics, meteorology, oceanography, the fishing industry, zoology, entomology, preservation of natural resources, museums, soils and soil classification, forest conservation, crop production, improvement of cattle breeding, coconut plantations, chemistry and natural resources, anthropology and social sciences, medicine and public health, and food.

The Soviet delegates took an active part in five sections (geology and geophysics, oceanography, the fishing industry, zoology, anthropology and social sciences) and presented 28 reports (six by the members of the delegation and 22 from other Soviet scientists).

The section on geology and geophysics was organized by the Seventh Session of the Pacific Congress in 1949. James Hily (Geological Survey of New Zealand) was the Chairman of the Permanent Committee of the section; its other members were: Litch and Morley (Canada), Charles Johnson, White, Revelle (U.S.A.), Allan (New Zealand), Fisher and Eger (Australia), Klompe (Indonesia), Alcaras (Philippines), Setkhaput (Thailand), Kobayashi and Minakami (Japan).

The Permanent Committee put forth the following problems for discussion at the Ninth Session of the Congress: 1) geological development of the Pacific region in the Pleistocene; 2) geothermy, including the study of heat currents, volcanism, and hot springs; 3) stratigraphic correlation of the sediments on the Pacific floor; and 4) participation in the program of the International Geophysical Year.

Forty-five delegates took part in the work of the section: two from the U.S.S.R., 18 from the U.S.A., nine from Thailand, three from Australia, two each from Vietnam and England, one each from Japan, Indonesia, the Netherlands, the Philippines, and Hong Kong.

Consistent with tradition, the first meeting was devoted to briefing on the results of research of the geologic surveys of the various countries surrounding the Pacific Ocean during the last four years. Let us mention only the major ones.

Canadian scientists have studied Pleistocene and post-Pleistocene volcanism along the Pacific coast of Canada and in the Yukon Territory.

The scientists of the U.S.A. have mapped the islands of Guam, Pagan, the Marianas, the Carolinas, and Ryukyu; they have also studied the history of the geologic development and structure of the northwestern part of the Pacific Ocean, the geology, oceanography, and geophysical phenomena in Bikini, Eniwetok, Rongelap, and Rongerik Atolls. Test drill holes have been made on a number of islands. They determined the thickness of the earth's crust in 21 places and recognized variations from 19 to 31 kilometers in thickness during oceanographic studies.

The geologists of New Zealand have completed the geologic mapping of the entire country at a scale of 1:1, 000, 000 and 1:2, 000, 000. They prepared a dioramic map at a scale of 4 miles = one inch; the map is scheduled for publication in 1958. They have carried out geologic and geothermal studies in connection with the construction of an electric power station (151, 000 kilowatts) at the Wairoa Geyser. Vapor geysers were discovered as the result of drilling.

The scientists of Australia have studied volcanism in the region of New Guinea, the Solomon Islands, and analyzed the data resulting from continuous observations on volcanoes in a number of regions.

A geological survey of Indonesia, headed by Professor Klompe, prepared a general geologic map of the country at scales of 1:2, 000, 000 (80 percent of the country), 1:1, 000, 000, 1:200, 000, and 1:100, 000.

Thailand has mapped 26, 000 square kilometers by airborne magnetic survey and found four anomalies. In a number of areas, airborne magnetic surveys were accompanied by airborne radioactive and electromagnetic surveys. Exploration for iron, tin, tungsten, manganese, gypsum, rock salt, and fluorite deposits is in progress. One third of the country was covered by hydrogeologic mapping. Geologic mapping is being carried out largely by geologists of the U.S.A.

The Philippine Bureau of Mines focused its attention on exploration for coal and strategic minerals of copper, chromium, manganese (in Central Cebu, Malangas, Bataan, Catanduanes, Bulalaco). The exploration data is published in ten volumes.

Japan summarized the data resulting from geologic mapping and from the study of mineral resources of the country.

A number of problems were discussed during seven sessions of the section on geology and geophysics from November 20 to 28. Besides, the section had united sessions with the section on oceanography, in which the questions related to radioactive poisoning of Pacific waters were discussed.

The first session of the section was devoted to the "nature, origin, and distribution of sediments in coastal areas of the Pacific Ocean" (under the chairmanship of Roger Revelle, Director of the Scripps Institute of Oceanography at the University of California U.S.A.). The following subjects were discussed: a) structure and division of the continental stage; b) historic development and present structure of bottom sediments and of deeper levels within the earth's crust.

Professor Warren Thompson (University of Alberta, Edmonton, Canada) presented a genetic classification of continental shelves which he divides into polar (formed principally by the action of glaciers), of intermediate latitudes, and tropical types. The characteristics of tropical shelves depends largely on the development of coral reefs. Thompson believes that shelves were formed in the Pleistocene and got their final forms during the Wisconsin glaciation. The shelf structures are greatly determined by vertical movements.

F.P. Shepard (Scripps Institute of Oceanography at the University of California, U.S.A.) presented detailed descriptions of submarine valleys on the shelf of southern California. The forms of the valleys are, according to him, determined by vertical movements of the ocean floor.

K.O. Emery (University of Southern California, U.S.A.) reported on the study of the forms and structures of submarine terraces by a sounding device in Japan, the Gulf of Iran, and southern California.

The report by R.F. Risher and R.R. Revelle (U.S.A.) presented the results of the study of submarine topography in the basins near the Aleutian and Kurile Islands, Japan, Ryukyus, Schouten Islands, the Marianas, Palau, the Philippines, Weber, New Britain, New Hebrides, Tonga, Peru, Chile, Acapulco (Mexico), Guatemala, and Cedros. They informed us that a submarine topographic map of the entire Pacific Ocean

s been published at a scale of 1:4,000,000.

The report by Warren and Stelka, U.S.A., ad by San-Aman, describes the history of insgressions of the epicontinental seas om the Precambrian to the Cretaceous.

San-Aman (California Institute of Tech- ogy, U.S.A.) briefed the section on seis- logy and structural geology on the compo- ion of the northwestern coastal area of nerica, Alaska, and the Kurile Islands, sed on aerial photographs.

Ye. V. Karus read the report prepared P.N. Kropotkin and Ye. N. Lyustikh S.S.R.) on the composition of the earth's ust and on the growth of continental sses.

The report by Hills (Melbourne University, partment of Geology, Australia) included ectonic map of Australia and New Zealand t divides the continent into three orogenic nes: Eo-Australia, Paleo-Australia, and so-Australia.

Gaskell (England) presented the results of smic logging in a number of Pacific gions (New Zealand, Caribbean Sea, West ast of the U.S.A.) and in the Indian ean. He demonstrated the possibility of logic mapping of the ocean floor by the smic method.

The second session (under the chairman- p of Grindley, Geological Survey of New aland) was devoted to the discussion of dies of Mesozoic orogeny in various parts the Pacific Ocean.

Doctor Grindley informed us that New aland consists of several Paleozoic and sozoic geosynclines. The Mesozoic struc- es strike east-west. Volcanism took place the Permian and the Cretaceous. In the ver Mesozoic, the geosynclines were partly ed in by volcanic products and partly by nitoid rocks. At the same time, the lower s of the geosynclines became metamor- sed.

Professor Klompe presented his viewpoint Mesozoic orogeny in southeastern Asia; ording to him, this orogeny was of great nificance in the development of structural ins near mountain ranges in these regions. e age determinations of granite exposed in southeastern part of the continent reveal t structural zones within the continent may traced to the Sunda Islands and Western onesia, where the formation of structures ed during the Pacific orogeny. The study the Indonesian geosyncline within the nd and Sea of Banda facilitated tracing it the eastern part of Indonesia. The Precambrian core of the Australian Plateau trends, according to Professor Klompe, due west and northwest. The belt of Variscan structures can be traced from northern Queensland to southern New Guinea, Ceram, and Sula Spur. He noted the differences in structural forms of eastern and western Indonesia.

Doctor Kobayashi (Japan) studied the Sakawa cycle of orogeny that followed the Permian and Triassic tectonism. This cycle was accompanied by intrusions in the district of Chuyukhu.

The third session (under the chairmanship of Professor Klompe, Department of Geology, Indonesian University of Bandung) was devoted to problems of volcanism and structural geology.

Professor Brouer (Holland) presented results of his theoretical studies on vertical and horizontal movements due to magmatic flows in his report entitled Orogenic and Cratogenic Volcanism. These movements produce large faults. He cited the confinement of volcanoes to large faults (e.g., Islands of Wetar and Alor).

Dr. Hills (Australia) presented a detailed division of Australia into platforms separated by geosynclines. Within the Eo-Australian zone, he cited belts of magmatism. The southeastern part of the continent has, according to him, zones of volcanism and ore mineralization. He outlined the relationship between volcanism, magmatism, tectonics, and mineralization.

Professor Fairbridge (U.S.A.) reported on deep sea measurements, sampling of bottom sediments, seismic surveys, and gravimetric surveys carried out by an expedition of vessels and submarines in the region of Melanesia. On the basis of these studies, the region of Melanesia, the Fiji Islands, and New Zealand were divided into various tectonic districts. He illustrated the relationship between a seismic belt and a large fault.

Grindley and Harrington reported on the study of post-Pliocene and Quaternary volcanism and its relation to structures of New Zealand. A number of reports were presented on volcanism in particular districts (British Borneo, Sunda Islands, New Zealand, Viet-nam, Japan, Kilauea, Hawaii, Sumatra, Keeling Islands, Mutu, and other areas).

The fourth session, devoted to the stratigraphy of the Pacific region, was under the chairmanship of Professor Kobayashi (Geological Institute of Tokyo University, Japan).

Professor Kobayashi presented the Jurassic stratigraphy of the Japanese Islands.

Hamilton and Rex, U.S.A., presented a systematic classification of the foraminifera and globigerina sediments in the region of the Marshall Islands. They presented a detailed stratigraphic classification of the Upper Cretaceous and Lower Tertiary sediments.

Jones (Malaya) introduced data on the basis of which the stratigraphic column of the Langkawi Islands, Malaya, and southern Thailand has been reviewed.

Dr. Hamilton described his theory on the consolidation of marine sediments. In the districts of phaseolin clays at a depth of 40 meters, consolidation of sediments leads to the formation of rocks with a 35 percent porosity. Chemical alterations turn these sediments into rocks having high seismic velocity; globigerina sediments may turn into rocks of extremely diverse physical composition.

The fifth session, devoted to the methods and techniques of geophysical exploration for the discovery of new mineral deposits, was under the chairmanship of Gaskell (British Oil Company, London). The reports disclosed that geophysical methods have been applied extensively in the region of the Pacific Ocean for the purpose of geologic mapping, structural studies, and especially in prospecting for mineral deposits. Seismic surveying is widely used, especially in prospecting for oil deposits, and airborne methods are used in prospecting for ore deposits and in submarine studies.

Dr. Hamilton presented materials on the "Bonita" expedition off southern California which carried out submarine geologic mapping. Geologists were provided with light diving suits, photocameras, radio receivers, rock hammer, and compass. The mapping can be undertaken down to a depth of 20 meters, and divers may remain under water for 15 minutes. He demonstrated a film showing the techniques of submarine mapping.

The report by Buds (Chief Geologist of Fairchild Aerial Surveys, Inc., U.S.A.), furnished the most recent data on geophysical logging of bottom sediments by a sounding device and the structural study of sediments on the sea floor in 14 districts of North and South America. He demonstrated the facilities for study of various structural types, selection of drill hole locations, and laying of cables and pipelines.

Rankin (Hunting Aero Survey, England) reported on the application of airborne geophysical methods in prospecting for ore deposits. He used a complex method that included airborne magnetic, gravimetric, radioactive, and electromagnetic surveys. Corresponding components of various geophysical fields were registered continuously. Simultaneously with the geophysical survey, color aerial photography, and determination of exact positions and elevations of each flight were carried out. Each geophysical anomaly found was, as a general rule, checked by a geophysical survey team on the ground.

Johnson (Capetown, South Africa) describe[d] the construction of a tellurometer, a new apparatus for precise determination of distances, using 10-centimeter radio waves.

Dr. Grindley described the application of geophysical methods for the geologic study of the district where the Wairoa Geyser Power Station was built, in which airborne magnetometric surveys and measurements of temperatures in drill holes were used. On the basis of thermometric data, the most suitable location for drilling for hot water and vapor was established.

The sixth session under the chairmanship of Professor Fairbridge, U.S.A., discussed the problems related to the growth and disintegration of coral atolls and the significance of physical abrasion in this process.

Finally, the seventh closing session, under the chairmanship of Vija Setkhaput, Head of the Royal Mining Administration of Thailand, reviewed the data on tin and tungsten deposits in the region of the Pacific Ocean. The reports were presented by Brenford (Geological Service of Malaya), De-Neve (Andalassa University), Bukhtindge (Central Sumatra, Indonesia), Kevadkhon and Arandjakopop (Mining Department, Thailand), Seksin, Vatanabi, and Sazoni (Geological Service of Japan), and Davis (Head of the Geologic and Geographic Faculty in Hong Kong).

The reports contained historical data on geologic prospecting, exploration, and mining, as well as a description of the geologic composition and nature of ore formations, types of ore bodies, and mineralogy and petrography of tin and tungsten deposits in Thailand, Malaya, Japan, and Hong Kong.

The tin deposits in Thailand have been mined since 1937, when mining of placers in the Changwatas,[1] of Phuket and Ranong began. The annual output of tin concentrates

[1] Administrative territory in Thailand that approximately corresponds to a province.

›r the last 25 years, from 1932 to 1956, veraged 8,522 British long tons, or 238,047 ı 25 years.

The mining of tungsten deposits started in 918 in the Changwata of Nakhon Sithammarat. rom 1935 to 1956 inclusive, 17,367 British ›ng tons of tungsten concentrate were ex- racted, or 790 tons annually.

The majority of tin and tungsten deposits re in southern, western, and northwestern hailand, in the districts where folded sedi- ıentary and metamorphic rocks are intruded / granites.

The tin and tungsten deposits in Thailand re of the following genetic types: placers, ydrothermal veins, contact-metamorphic ›dies (tin deposits only), impregnations, and ›lite bodies (magmatic segregations), peg- atite and aplite dikes.

Tin and tungsten in rock deposits may ccur together or separately. These deposits re generally related to granite intrusions at least two different ages, of which the rst is presumably of Permian or Triassic ıd the second of Upper Cretaceous age.

The principal tin production is derived om placer deposits, while that of tungsten from residual or bed rock deposits. ost of the tin and tungsten concentrates ined in Thailand are exported.

Ye. V. Karus presented four reports: that by P.N. Kropotkin and Ye. N. Lyus- ch entitled Pacific Type Structure of the ırth's Crust and the Origin and Growth of ›ntinents; 2) one by P.N. Kropotkin entitled ındamental Tectonic Characteristics of the nur River, Sikhote-Alin, Kurile Islands, ıd Kamchatka Regions; 3) one by Ye. V. ırus, Absorption of Elastic Waves by Rocks; and one by L.S. Veytsman, Ye. I. ıl'perin, I.P. Kosminskaya, and Yu. V. znichenko, entitled Study of the Earth's rust in the Area of the Asian Continent. ıe last two reports stimulated questions and scussion.

During the meeting there were a number receptions, for both the entire congress d for certain sections. These receptions, ven by the Royal Mining Administration of ıailand, contributed to mutual acquaintances d to unofficial discussion of certain scien- ic problems.

The Mining Administration is headed by ja Setkhaput; technical managers were hnson and Gardner, American advisers. ıe equipment and machines are of British d American manufacture. The fundamental m of the Administration is the management of the geological survey and mining of ore deposits (especially of tin and tungsten). The staff consists of 26 geologists with college degrees from abroad.

The Administration has the following departments: Geological Survey, Exploration of Mineral Deposits, Mechanization, and Publication, and a number of units for scien- tific work in the fields of ore processing, experimental metallurgy, chemical and spec- trum analysis. The Administration carries on a number of interesting research projects.

Both during and after the sessions, there were a number of one-day and longer field trips. Among them were trips to the Pasteur Institute, the marble temple of Buddha, the Parliament building, the fish bazaar within the city, a one-day trip to the village of Lopburi, organized by the Department of Public Health, to the water reservoir of Sublek, to the village and temple of the Buddha of Saraburi built on the spot where a footprint of Buddha was found (Prabuddhabad), a one-day trip to the water reservoir of Bang-Pra, to the Marine Station of the Geo- graphic Administration at Sattahip, and to Kokram Island where marine turtles are bred, and around which there are coral reefs, a one-day trip to the Biological Sta- tion of the Bang Saine University, a trip to the old capital of Ayudhya and to the royal summer palace of Bang-Pain -- all of which were very impressive.

From December 6 to 9, the Soviet dele- gation took part in a three-day field trip to the Khorat Plateau, City of Nakhon Ratcha- sima, the village of Pimai, for inspection of the ruins of the Khmor temple built in the 17th century and for inspection of silk manu- facturing. This field trip acquainted our delegation with a new kind of topography and gave them an idea as to how difficult the cultivation of a great territory can be.

During the three weeks of the Congress, the Soviet delegation had an opportunity to become convinced of the breadth and variety of the problems discussed in the various scientific fields. The delegates gained much from personal communication and meetings with the great scientists of the world. We got acquainted, perhaps inadequately, with the country and capital of Thailand.

For the opportunity and care given to the Soviet delegation, we are sincerely grateful to the government and scientific societies of Thailand. The success of the Congress was greatly enhanced by the excellent organiza- tion of the sessions and field trips.

The Soviet delegation became acquainted with many scientific and cultural institutions

in Bangkok and with outstanding memorials of older times, demonstrating the highly developed old culture of the people and the great progress reached by it now.

The Soviet delegation has no doubt that the Ninth Session of the Pacific Congress, the meeting of scientists of various countries and their mutual efforts contributed tremendously to the consolidation of friendly relations between various countries and to the further advancement of the sciences.

BRIEF COMMUNICATIONS

ON SECONDARY ALTERATION AND AGE RELATIONSHIPS OF EXTRUSIVES AND THEIR CHARACTERISTICS IN THE SOUTHERN PART OF THE SOVIET FAR EAST

by F.V. Petrun'

In the Izvestiya, Akademiya Nauk SSSR, riya Geologicheskaya, No. 7, 1956, M.A. ivorskaya published an article entitled condary Alteration of Acidic Extrusives in e Southern Part of the Soviet Far East, e same subject as her earlier publications , 6, 7]. This article actually consists of description of the Oligocene extrusives at are exposed along the shore of the Sea Japan between the Point of Balyuzek and e mouth of the Tadush River. I visited is district twice during the summer and in e fall of 1954 when I was engaged in geo- gic mapping in the Far East. Since the sults of my studies on the same exposures ffer essentially from those described in the ticle by M.A. Favorskaya, I believe it is cessary to express my views on the sub- ct.

The extrusives exposed along the sea- ore south of the mouth of the Tadush ver are more brightly colored than simi- r extrusives that crop out farther inland. nce all kinds of extrusives show similar eaching at the seashore, the geologic use of this phenomenon must be common r all the rocks concerned. The phenomenon viously is caused by superficial alteration ich is more intense at the seashore be- use of the absence of a soil blanket, the gher salt content of the sea water, and her factors that intensify bleaching. tually, in underground workings, in places recent avalanches, or where erosion is ore rapid than superficial alteration, less tered, slightly bleached rocks are exposed; eir color ranges from dark gray or brown nearly black but is never uniform. The ottily distributed, light-colored areas thin unbleached rocks of an outcrop do t everywhere show signs of postmagmatic etasomatism, which they should, according M.A. Favorskaya's conclusions. Besides, eaching is not restricted to extrusives. early pronounced bleaching occurs, for example, in black tuff lavas of andesite and dacite composition [7, 1] that are exposed directly at the seashore, 5 kilometers west-southwest of the Point of Yuzhnyy.

The bleaching of extrusive rocks due to obvious hydrothermal activity may involve these and older extrusives of the district (for example, east of Lake Topauz or north of Nerpa Bay), but its occurrence, forms, extent, and specific mineralization differ essentially from those of superficial alteration. Furthermore, in describing outcrops north of the Point of Yuzhnyy, shown in three accurately drawn illustrations,[1] M.A. Favorskaya attempts to substantiate her concept that the alterations are exclusively postmagmatic, but in so doing she allows a number of inaccuracies. For example, in Figure 2 attached to her article [8] she shows: 1) brown obsidian in the form of a vein; 2) brown tuff lava; 3) black tuff lava, while in Figure 3 the same units are termed: 1) brown tuff lava; 2) black tuff lava; 3) boulders of black obsidian enveloped by brown tuff lava.

In the text, however, for reasons unknown to us, the obsidian shown in the figures is termed a variety of dense tuff lava, which, according to her, supposedly differs under the microscope from the normal variety of ignimbrite "only by a slightly lower glass content" ([8], p. 74). First of all, this is incorrect and contradictory to the classic description of tuff lavas, i.e., ignimbrites of this region, given by M.A. Favorskaya herself [6], and secondly it leads to an erroneous conclusion concerning their origin, i.e., to restriction of the brown tuff lavas to contacts of other rocks differing in density, or to block-forming or spherical joints.[2] M.A. Favorskaya does not explain

[1] Throughout this article I will repeatedly refer to these illustrations ([8], Figures 1, 2, and 3), since the typhoon of September 1954 did not permit me to take photos of the outcrops from the sea and restricted my study to a thorough observation of shore exposures, to the same kind of drawings and to collecting samples.

[2] The spherical joints we did not see in tuff lavas anywhere in clearly recognizable form. They occur only in real lavas.

the occurrence of the vein-like bodies and the thickness of glassy rocks shown in Figure 2 of her article [8]. According to her text (p. 72), the dip of tuff lavas, recognizable because of the lens-shaped inclusions of volcanic glass, does not exceed 25 degrees, while in the attached figure (and in the outcrop), a vein-like body dips at least 50 degrees relative to a horizontal line (vertical boundary of the figure). If the flattened obsidian inclusions, occurring in tuff lavas, form lenses whose thickness is insignificant [6] one can hardly interpret the form and extent of the vein-like bodies in a similar way, even in referring to the most fanciful volcanic bombs of any composition. Thus, contrary to M.A. Favorskaya's general conclusions, the figures in her article [8] do not illustrate the presence of two varieties of tuff lavas differing in density. In reality, an observer without prejudice sees tuff lava (partly black, partly brown) cut by independent extrusives differing from enclosing rocks in composition, structure, texture, and age. Several vein-like bodies of this type occur in an area 7 kilometers long between the Point of Yuzhnyy and the Bay of Nerpa. Their form, within the exposed part, is even more complicated than in Figure 2 of M.A. Favorskaya's article [8]. Combined and branching, not single, vein-like bodies occur here. They do not everywhere die out within one to five meters above sea level but more commonly extend, without interruption, along the entire height of cliffs for a distance of 50 to 80 meters, cutting through the enclosing light brown tuff lavas.

Such veins frequently change their dip (from 15 to 20 degrees) and strike, and have numerous apophyses and branches, interruptions and thickenings. These thickenings look like "inclusions" of various sizes of volcanic glass in tuff lavas, shown in all the figures by M.A. Favorskaya [8]. However, they can by no means be considered constituents of tuff lavas, for their contacts are everywhere discordant and sharp, despite the secondary alterations that somewhat obscure the contacts because they are developed in obsidian along fine fractures. They are not pseudo-dikes (like those described by M.A. Favorskaya in 1949),[1] for they consist of glassy liparite but not of metamorphosed tuff. It seems that their unusual "nondike-like" appearance and sharply-changing thickness and strike led M.A. Favorskaya to an error in her field interpretations. Only by carefully tracing, meter by meter, along the cliff wall and looking from the sea (at a distance of 50 to 100 meters from the shoreline), which cannot be done without risk, can such an error be avoided.

The lateral distribution of such zones along the shore clearly shows their confinement to certain bands. They occur within narrow (50- to 100-meter) bands of coastal cliffs. Within the bands, the rocks are cut by these vein-like bodies, while farther on no glassy veins can be seen for several hundred meters in uniformly light-colored tuff lava, in places cut by altered andesite and basalt dikes. Then the next band, rich in glassy veins, is exposed. The andesite and basalt dikes differ from the above-mentioned veins because the dikes have well-defined straight contacts and uniform dip. The dark-colored glassy veins are clearly visible against the background of light brown tuff lavas because of their color and glassy-to-fatty luster.[2] Small veinlets of such postmagmatic and hydrothermal minerals as opal, chalcedony, quartz, carbonates, and zeolites commonly occur along the contact of glassy veins, but they may also cut the veins and the andesite basalt dikes, which are always altered to some extent.

Microscopic study disclosed that brown or red-green tuff lavas are formed partly as a result of superficial alteration of the glassy mass of black tuff lavas, but the crystallization of their glassy matrix is much further advanced than that of glassy veins in inclusions (Figures 1 and 2).

The matrix of ignimbrites carries all the signs indicating their origin, such as coarse-fluidal texture, and frequently eutaxitic, as a result of a more intense alteration of better crystallized bands relative to the bands in which crystallization is less advanced (microfelsitic or cryptocrystalline aggregates of quartz and potassium feldspar whose indices of refraction range from 1.526 to 1.530 $\pm$ 0.002). Almost every case shows clear relicts of forked or crescent-shaped pieces of volcanic glass, up to 0.1 millimeter long, and numerous fragments of larger phenocrysts of quartz and feldspar. Both black and brown tuff lavas contain feldspars that carry signs of secondary alteration (pelitization, albitization) largely confined to cleavages, but in places also developed in internal parts of the grains. On the other hand, the black volcanic glass, that according to M.A. Favorskaya is identical with black tuff lavas, actually differs from the latter because of its porphyritic (sometimes nevaditic) structure, hyaline

[1] Forms close to the pseudo-dikes defined by M.A. Favorskaya [5] were found near Nerpa Bay (observation point 3662).

[2] The luster of the glassy veins disappears in advanced postmagmatic alterations, and they do not break conchoidally.

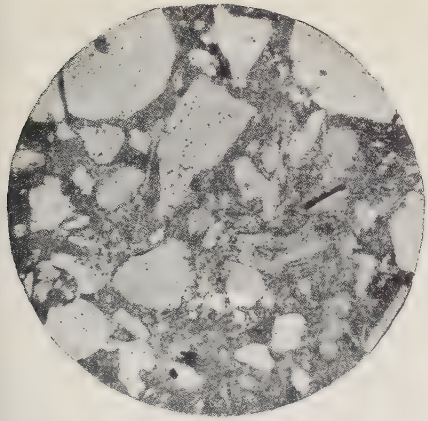

Fig. 1. Dark brown (black) tuff lava with coarse, fluidal texture.

Heterogeneous, slightly crystallized, and pelitized (and therefore less transparent) matrix contains numerous obsidian pieces in various forms. Feldspar grains are altered along cleavages. There are quartz, biotite, and ore minerals. Without analyzer. Magnified 13X.

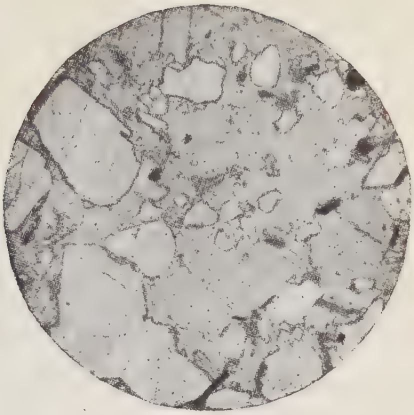

Fig. 2. Black, glass-like liparite from a vein-like body.

Exceptionally uniform matrix in which fine microfluidal texture is recognizable only at adequate enlargement. Feldspar grains are not altered. Light grains with conchoidal fracture are quartz grains; opaque grains are ore minerals; elongated gray to dark grains are biotite. Without analyzer. Magnified 13X.

atrix (without any sign of crystallization) ıd fine microfluidal texture. A similar texre may also occur in other veins of glassy ›mposition, but here the flow lines may ʼen be transverse to those of the enclosing nimbrite.

Thick slides show numerous curvilinear actures cutting through the glass matrix, ıile such fractures never occur in tuff vas. Phenocrysts of glass rocks are less actured than those of tuff lavas and are ›ver pelitized.

The glassy liparite[1] has a much higher O_2 content than liparite described by .A. Favorskaya [7] or the enclosing tuff vas of biotite liparite (Table 1). This also dicates that the tuff lavas are younger than e enclosing liparites. As early as in 1949, .A. Favorskaya noticed a continuous (from e Upper Cretaceous to the Miocene, inclusive) change in the composition of the magatic rocks in this area; the change leads a higher alkaline and silica content and a decrease in alkaline earth elements in ›unger rocks. The tuff lava discussed here clearly differs from black tuff lavas occurring south of Lake Topauz, considered by M.A. Favorskaya a derivative of dacite magma, but it shows certain similarities to the liparite of Veselyy Yar (Table 1, Assays I, II, IV, and V). The high alumina content in both and their similar mineral composition indicate their formation at about the same time.

Liparite (rhyolite, quartz porphyry, and their tuff lavas) have erupted many times in the Olga-Tetyukhe district. It is natural, therefore, to assume that liparite dikes south of the Topauz River are volcanic vents, synchronous with tuff lavas south of the Point of Yuzhnyy, while the glassy veins cutting the former are vents of glassy lavas from higher stratigraphic levels, of lavas which, along with ignimbrite of acidic composition, form the top of the Brusilov group, overlying the coal-bearing Oligocene sequence of the Tadush Depression [1]. The rock formations discussed here obviously had the same function as the necks or feeding channels termed "intrusive dikes"[2] in older textbooks ([3], p. 107). Such necks are irregularly shaped,

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Refraction index of the glassy rock (Sample 724 B, a black tuff lava according to M.A. ıvorskaya -- in reality, a black glass) is 496 + 0.002 (this and other determinations e with white light), and this also indicates idic composition of the rock.

[2] They seem to be abundant; let us cite glass intrusions in dolerite, described, for example, in [4]; in a number of cases they are, however, simply left beyond consideration as did M.A. Favorskaya in this area, although I.I. Bersenev points to eruptive contacts of tuff lavas and vitrophyric porphyry-liparite ([8], page 75).

Table 1

Chemical Components	I	II	III	IV	V
SiO_2	65,06	72,89	70,16	75,14	74,73
TiO_2	0,60	0,28	0,25	0,18	0,16
Al_2O_3	17,00	14,19	13,55	13,02	13,99
Fe_2O_3	1,70	1,46	1,17	2,33	1,31
FeO	3,00	1,25	1,46	0,29	0,29
MnO	0,09	0,05	0,09	0,03	0,05
MgO	1,70	0,56	0,67	0,27	0,32
CaO	4,13	1,35	2,48	0,45	0,74
Na_2O	3,60	3,64	4,25	2,66	4,27
K_2O	2,40	3,32	1,95	4,78	4,19
P_2O_5	0,10	0,05	0,03	—	—
$H_2O+110°$	1,30	—	—	1,07	0,33
$H_2O-110°$	0,13	0,62	1,35	0,35	0,41
Loss on ignition	—	0,82	2,92	—	—
Total	100,81	100,48	100,33	100,57	100,79

I. Dacite tuff lava. Analyzed by O.A. Alekseyeva [7].

II. Biotite liparitic tuff lava, Sample 10724 A. Analyzed by A.N. Akselrod (VSEGEI).

III. Black glassy liparite, Sample 10724 B. Analyzed by A.N. Akselrod.

IV. Liparite. Analyzed by O.P. Ostrogorskaya [7].

V. Liparite of a dike. Analyzed by O.P. Ostrogorskaya [7].

Composition Indices According to A.N. Zavaritskiy's Classification

	a	c	b	s	a′	f′	m′	c′	n	φ	t	Q	$\frac{a}{c}$
I	11,4	5,0	8,8	74,7	16,4	51,0	32,7	—	70,0	17,1	0,73	21,7	2,3
II	12,4	1,6	6,0	80,1	45,6	39,1	15,2	—	62,7	19,5	0,28	34,6	7,8
III	12,3	3,0	3,7	81,0	—	66,2	30,9	2,8	76,9	26,1	0,30	46,6	4,8
IV	12,3	0,6	5,8	81,2	55,4	37,0	7,5	—	45,9	32,0	0,24	37,3	20,5
V	14,8	0,8	3,2	81,1	41,0	42,5	16,5	—	60,5	32,7	0,16	21,9	18,5

erally dike-like but not pipe-like volcanic nnels of small thickness, presently occur- ; in the form of "completely hardened" sy masses. They could be formed under cial geologic conditions. Unlike platy s, they were most likely a combined ılt of faulting[1] and penetrating action of es, and consequently indicate the degree ctivity of ascending magma and its lacement close to the surface [2].

The fact that the volcanic channels in this rict are very abundant within a distance even kilometers and their geologic char- ristics do not change (including form, kness, relation to enclosing rocks, min- composition, etc.), suggest the shallow h of the volcanic source and the possi- y of areal extrusion of lava. On the r hand, the presence of andesite-basalt s along with liparite dikes, suggest dif- ng conditions under which the volcanic es were formed. This fact itself deserves ough study and consideration. The tec- c activity that accompanied volcanism h of the mouth of the Tadush River can nore easily defined qualitatively and ntitatively than the alterations of acidic usives described by M.A. Favorskaya. al alterations (to a greater extent super- l than postmagmatic or hydrothermal) ot be denied.[2]

n studying regions of recent volcanism, as that in the southern part of the et Far East, one must correlate, com- and recheck the data of various inves- ors more thoroughly than anywhere else, cially those of investigators who belong arious scientific schools and orientations; should not fail to combine general works a thorough geologic mapping of the . Such works may supplement each r and facilitate the reconstruction of the ogic past of this particular part of the East more or less reliably. The solution uch complex problems cannot be achieved through the efforts of a single, even most thorough, investigator.

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ie volcanic vents of this area may be ten- fractures of irregular "equant" forms, mon in the Olga-Tetyukhe district; they usually considered indications of a near- ace origin, under a thin or medium-sized ket of overlying layers.

far as the district between the Point of nyy and the Bay of Nerpa is concerned, rea to which M.A. Favorskaya's descrip- and drawings refer, we can hardly agree her reasoning in presenting it as an area ntinuous postmagmatic metamorphism, h consequently denies ([8], p. 75) the ently existing and unquestionably eruptive ionship between liparitic tuff lavas and s of glassy extrusives of about the same position but of different age.

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Mining Institute of Krivoy Rog

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HELGE BACKLUND

Helge Backlund, a meritorious professor at Uppsala University in Sweden and an outstanding petrographer with broad geologic interests, who was well-known to Soviet geologists, died in January 1958.

Helge Backlund was born in 1878 in the city of Tartu (formerly Dorpat, Yur'yev), Estonia. His father was a well-known Swedish astronomer, at that time professor at the Yur'yev (now Tartu) University. H. Backlund received his education in St. Petersburg and from 1902 to 1917 he was with the Geological Museum of the Russian Academy of Sciences. During this period he took part in a number of expeditions, e.g., to Spitzbergen, the polar Urals, and the polar regions of Siberia; he published over 30 articles in the periodicals of the Academy of Sciences and in other Russian magazines. His works on crystalline rocks of the Taymyr and Anabar massifs, based on a study of the collections made by the expeditions of the Academy of Sciences, are especially well known. They present the data of petrographic studies -- excellent for his time -- of rocks sampled in the regions investigated for the first time and contain a wealth of interesting geologic data. Also, H. Backlund later wrote for Soviet geologic magazines.

From 1917 to 1924, H. Backlund was a professor in Turku (Swedish Abo), Finland, and from 1924 to the end of his life he was a professor at the University of Uppsala. From 1912 to 1913, H. Backlund was a State Geologist of Argentina, where he studied the Andes. Later he undertook geologic studies in Scandinavian countries, Iceland, Greenland, Spitsbergen, and the Faroe Islands, and made numerous geologic trips to various European countries, Caucasia, Outer Mongolia, and other places. H. Backlund was in constant communication with Soviet geologists and gave interesting scientific lectures. In 1937 he reported on principles of stratigraphic division of the Precambrian, at the Seventeenth Session of the International Geological Congress in Moscow, and in 1945 in the session devoted to the 220th anniversary of the Academy of Sciences of the U.S.S.R. he presented a report on Precambrian bituminous shale of Sweden and on their uranium and trace element content

H. Backlund spoke good Russian with a slight accent. His friends joked that he sp all languages and all of them equally badly In his articles published abroad, H. Backlu referred extensively to Russian literature. He was very simple and cordial -- a man of good will toward everyone. The Soviet geologists who met him cherish their warm memory of him.

In his work, H. Backlund concentrated h greatest attention on the study of metamor phism and magmatism and their relationshi to tectonics. H. Backlund's work on granit zation, based on many years of study of t Scandinavian Precambrian, are widely know

The first decades of our century was a period of universal enthusiasm about the physical and chemical ideas of I. Vogt, N. Bowen, and others concerning magmati processes. At that time, a hypothesis on granitization, anatexis, and palingenesis w developed by the Finnish geologist, J.J. Se erholm, whose concepts were sharply criti cized. H. Backlund was a student of J.J. S erholm, and after the 1930's he developed Sederholm's ideas on granitization still fur ther and defended them in a number of pub lications. H. Backlund was an advocate of the metasomatic origin of granite, which, according to him, resulted from diffuse "emanations" reacting with crystalline rock which may become partly molten. Thus, according to modern terminology, Backlund may be included in the group of scientists classified as "transformists." His hypothes on the formation of the Rapakivi granite massif in Finland, as the result of the gra itization of Iotnian sandstones, explains the sill-like form of this massif.

There are frequent references to H. Bac lund's hypothesis on eclogites. Following other authors, he considered their formati to be the result of exceptionally high pressure and expressed an interesting viewpoin that high pressure of this type may be achieved in certain regions of high tangent stress even at moderate depths, i.e., und a moderately thick overlying mantle. This

explain the extent to which eclogites are
ied to relatively young (for example,
e) fold zones. Among Soviet geologists,
Sobolev draws similar conclusions.

Backlund also published articles on
rous other problems of petrography,
nism, stratigraphy, tectonics, general
gy and geography. All his publications
nstrate the broad geologic knowledge
e author; they are constantly cited and
the development of modern scientific
gic concepts.

ıch of his time he devoted to education
e University of Uppsala, where he
t numerous students. Besides lectures,
ent much time in organizational and
iistrative work, as he said himself
he was in Moscow.

He equipped the university with modern optical apparatus and left a memory of himself as a professor of the highest rank.

On the occasion of his 65th birthday, the Geologische Rundschau wrote: "Helge Backlund has not become an authority. His adversaries criticize him for this, but his friends and students are grateful to him for this."

We will remember H. Backlund as an indefatigable investigator who contributed much to the study of the northern part of the U.S.S.R. and as an outstanding geologist and an exceptionally cordial man who was always very friendly toward Soviet geologists.

D.S. Korzhinskiy

REVIEWS AND DISCUSSIONS

ON THE SYMPOSIUM "PROBLEMS OF THE MINERALOGY OF SEDIMENTARY FORMATIONS" BOOK 3-4[1]

by N. M. Strakhov

Soviet sedimentary petrology has developed rapidly and successfully during the past 15 to 20 years, especially since World War II. The recently published reports presented to the Conference on the Mineralogy of Sedimentary Formations that took place in May 1955 in Lwow give ample support to this statement.

The symposium of reports consists of seven sections: 1) General problems of sedimentary mineral formation (nine articles); 2) Formation of sedimentary ore deposits (nine articles); 3) Mineralogy of chemical sediments (four articles); 4) Regional mineralogy and identifiable minerals of sedimentary formations (14 articles); 5) Alteration of sedimentary formations (five articles); 6) Mineralogy of clay (five articles); 7) Methods of investigation of sedimentary minerals (three articles) -- a total of 48 articles. The great number and variety of the articles demonstrate the extensive and wide approach of Soviet geologists to the study of authigenic minerals of sedimentary rocks.

The symposium aroused tremendous interest, partly because of the clearly expressed theoretical concepts.

The history of any rock includes three consecutive stages: sedimentation, diagenesis, and epigenesis.

Even recently the principal attention of sedimentary petrologists was confined to the stage of sedimentation. The formation of the overwhelming majority of authigenic minerals was believed to have occurred in this stage and was interpreted by the processes of chemical differentiation within the sedimentary basins concerned. Diagenesis and epigenesis have been presented in vague and unclear outlines and their significance in authigenic mineral formation was believed t[o] be small.

The study of contemporary sedimentation, however, revealed beyond doubt that concep[ts] like this concerning the course of authigenic mineral formation are wrong. Sedimentation on a sea floor actually means nothing but accumulation of raw materials, but authigen[ic] mineral formation that produces stable minerals takes place principally during the stages of diagenesis and epigenesis. Thus, most of the study of authigenic mineralogy moved from sedimentation to the next stages, first to diagenesis, then to epigenesis, and authigenesis itself becomes a complicated process consisting of several stages.

The reports published in the symposium are significant because of the fact that a great number of sedimentary petrologists adopted the new point of view in the interpretation of the origin of authigenic minera[ls]. This new theoretical concept was clearly reflected in both the reports of general scientific nature (for example, by D. P. Bobrovnikov) and in special communications concerned with diagenesis (N. M. Strakhov) and epigenesis (L. B. Rukhin, A. G. Kossovskaya, and V. D. Shutov). The concept was especially emphasized in the reports concerning the mineralogy of the sedimentary ore and coal deposits (S. I. Beneslavskiy, A. U. Litvinenko, V. F. Malakhovskiy, V. I. Gryaznov, S. I. Kulikov, T. S. Dzotsenidze, N. I. Skhirtladze, I. D. Chechelashvili, and M. A. Rateyev). This fact is especially valuable. The situation becomes even clearer if we take into account that at the conference and in its transactions, there were no work[s] reflecting the older sedimentary concept on authigenic minerals and no attempts were made to revive, support, and develop the idea of chemical differentiation in water basins as the principal process of authigenic mineral formation in sedimentary rocks.

From this point of view, the Lwow conference of 1955 meant the beginning of a new period in the study of sedimentary rock[s], a period of staged analysis. It is understoo[d] that our knowledge on the subject is still limited and of a preliminary nature, but the approach itself is very promising and deserves further development. Detailed and comprehensive study of diagenesis, epigene-

[1] Lwow University Press named in honor of I. Franko, 1957.

and early metamorphism, as I have em-
ized previously, is the most urgent
lem of theoretical sedimentary petrology.

n conclusion I must stress one more
ct of the problem.

he first All-Union Conference of sedi-
tary petrologists in Moscow in 1952, in
h over 100 sedimentary petrologists took
, overwhelmingly favored the publication
special sedimentary petrology magazine.
refore, the initiative of Lwow University
e publication of periodical symposia,
d by Ye. K. Lazarenko and devoted to
ralogical Problems of Sedimentary For-
ons is even more valuable. Of these
posia, three volumes have already been
ibuted, including the third double volume.

he review of the contents of the sym-
, especially those of the third volume,
h includes the reports presented to the
Conference of 1955, discloses the
t scientific value of the publication
ted by the Lwow University, and this
tive will find enthusiastic approval and
ort.

ON THE REVIEW OF D.V. RYZHIKOV'S BOOK "THE NATURE OF CAVES AND THE BASIC FEATURES OF THEIR DEVELOPMENT,"[1] by N.A. Gvozdetskiy, N.I. Nikolayev, and D.S. Sokolov

by D.V. Ryzhikov

n article by N.Z. Gvozdetskiy, N.I.
ayev, and D.S. Sokolov, entitled
cerning D.V. Ryzhikov's Book, The
e of Caves and the Basic Features of
Development appeared in the Izvestiya,
emiya Nauk SSSR, Seriya Geologiche-
, No. 11, 1956, pages 117-120.

e authors note some positive aspects
book, but as a whole they believe
presented a one-sided and narrow
standing of caves as the result of
ogeological processes" (p. 119), and
he basic features of their development
esented according to my concept are
rect and conflicting (p. 118). Is this
My book is, of course, not without
comings. A number of failures and
comings (p. 120, fifth paragraph from the bottom) have been noticed by the reviewers, and I agree with them. As a whole, however, the reviewers did not show adequate objectivity in evaluating this work. Let us cite the principal points questioned by the reviewers.

1. They state that a number of points, such as those concerning "the existence of underground streams and the movement of water derived from fractures," as well as the "reasons for a horizontal distribution of caves," etc. (p. 118) have been previously expressed in the literature but that the author claimed to have expressed them for the first time. This statement is not true (see pp. 22, 51, 56, and other pages).

On the contrary, I developed these concepts and demonstrated that a rock layer bearing free water and cave streams are two sides of a single process, which at a certain stage of development support each other, but at other stages retard each other (pp. 90-92 and other pages). The reviewers, however, for reasons unknown to me, ignored this statement. The same is true in the case of the horizontal distribution of caves and cave development below the water table.

2. The reviewers disagree with me that the "decisive factor" in the development of caves is "the formation of a water table confined to caves (the properties of the water table and its up or down motion depending on the sign of epirogenic movements)," and they blame me as if I "denied the cooperative action of surface and subsurface waters in the development of sinkhole topography" (p. 118). This is wrong. The opposite can be realized, for example, from the fact that I spoke of three sources feeding cave waters, of which two are surface waters: a) atmospheric precipitation within the area of sinkholes (about 60 percent of the total water becoming ground water); and b) river water (large and small streams) soaked by the ground water of caves after its entrance into the area of sinkholes (20 percent of the total ground water received). Of course, both the atmospheric and river waters react with the wall rocks of caves and consequently affect the formation of solution topography. Blind gullies, blind branches of dry valleys ending in sinkholes, and sinkholes themselves, karren and karrenfelder result, I believe, because of the action of superficial water. However, a sinkhole topography is formed primarily because of the action of subsurface water. This is evident, for subsurface streams prevail over those surface streams in caved areas. Caved areas actually are "hydrologic anomalies."

3. The reviewers state that "the author misuses the term 'cave water'" (p. 118).

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1 dy of the Mining and Geological Institute
Ural branch of the U.S.S.R. Academy
ences, No. 21. Academy of Sciences
, Moscow, 1954 (Page 154, Figure 55).

They disagree with my concept that "water in limestones overlain by thick strata of various sandy, clayey, and other impermeable rocks cannot actually be considered cave water." They obviously take for granted that these waters, because they are confined to rocks within which caves can be formed, should also be included under cave waters. But this point of view is completely wrong. Cave waters, as I have shown, are exchangeable, have their independent feeding and discharge areas, and the conditions of their existence and composition are not related to those of subsurface waters saturating the country rock. On the other hand, water in limestones overlain by thick strata of barely soluble rocks, such as water in limestones below the sea bottom, do not, of course, have the same characteristics as cave water. Water in deep-seated limestones are usually fracture waters which have all the peculiar characteristics resulting from high pressure, such as retarded circulation, insignificant exchange, high mineral content, etc." (pp. 79-80).

4. The reviewers write that "the author's concept of the patterns of watersheds is filled with discrepancies" (p. 119), and to prove this they quote several sentences taken from various parts of my book. They say that the author first mentions that in caves areas "caves are most abundant near valleys" (p. 68) but later states that under interfluvial divides "there may occur, and in the majority of cases, really do occur, as many caves as there are near valleys" (p. 69). But in the second sentence they disregard the words "may occur" and drop the comma after "do occur" (p. 119) in an attempt to make their statement more "convincing." However, even in this form there is no particular discrepancy. Under interfluvial divides there really do occur as many caves as there are near valleys. This is especially true in typical cave areas, where we should actually study the nature of caves and their evolution.

5. On the one hand, the reviewers agree to a certain extent with the basic patterns in the development of caves as set forth by me. They write that this concept "is an explanation of the development of dry valleys and partly of that of large horizontal caves" (p. 120). On the other hand, they deny the concept completely, because they state that "the author's claim that his viewpoints reflect 'the principal regularity of cave evolution' must be rejected" (pp. 119-120). It should be remembered that the fundamental rules of evolution or the essence of any process, including the formation of caves, cannot be universal, manifold, and all inclusive. Essence, unlike phenomena, is always schematic and narrow.

The development of caves rests princip[...] I believe, upon universal adjustability of cave water to its environment, first of al[...] to local surface and subsurface drainage bound to each other by some kind of "dynamic" water table. Each base of eros[...] controls the drainage of a certain area of ground water. The draining capacity of th[...] base is determined by the energy that depends on the position of the adjacent grou[...] water. Each base tends to gain an additio[...] feeding area at the expense of a neighbori[...] one, and consequently the subsurface inte[...] fluvial divide between them moves toward[...] weaker base, and the ground water table [...] the particular area drops (during positive epirogenic movements). As a result of rivalry and conquest of the ground water [...] a stronger, deeper base, transitional bas[...] turn into dry valleys or dry cave levels [...] ing a certain stage of the evolution and th[...] water table becomes separated from the [...] local bases.

The reviewers state that caving is "a more complicated and comprehensive pro[...] that depends on the lithologic composition[...] permeability of rocks, tectonic structure[...] topography, climate, chemical compositio[...] of water, etc." They claim that I did no[...] consider these factors and "in doing so" supposedly "turned caving into a hydroge[...] logic process" that develops without bein[...] affected by the environment (p. 120). Is t[...] true? No -- it is wrong. First, the poin[...] the reviewers, as the above consideratio[...] reveal, contains obvious contradictions a[...] inconsistencies. I did not deny or underestimate the necessity of considering the effect of all these factors upon the devel[...] ment of caves (lithologic composition of rocks, their permeability, tectonic struc[...] etc.), but I went even further, as can be seen from the entire content of the book, [...] say that in order to realize the essence [...] cave development one must find specific features and patterns of evolution caused [...] the above factors. I did that. The nature [...] cave development, as presented in my bo[...] is related to the rivalry of transitional b[...] controlled by epirogenic movements and [...] strong bonds with all the particular featu[...] and patterns of the evolution of caved ar[...] This proves adequately that I did not sep[...] ate the evolution of caves from their env[...] onment.

Do the reviewers present any new poi[...] of view concerning the nature of caving? No. In connection with this, it must be [...] that arguments concerning the origin of [...] holes or other cave forms do not have a [...] basis. Without knowing the nature of the evolution of caves, one can at best spea[...] only of morphologic classification of one [...] another form of cave. This is actually d[...]

e reviewers.

The reviewers consider that my ussion" of an example that illustrates :he principal pattern of cave develop- can be utilized for hydrotechnical con- tion is "erroneous" (p. 120). Let us f this statement is correct.

ı pages 123 to 125 of my book, I wrote :he filtration -- in other words, the of water -- from a basin occupying a l area must be considered from an tially different point of view than that basins occupying non-caved areas; if n is built in one of two parallel valleys beds are at about the same elevation, long which approximately the same nts of water run, water can be lost the dam even in cases where the water within the interfluve area is at the level as the dam or even higher. The icement of the subsurface interfluve d the weaker base of erosion, i.e d the valley in which the dam was and the drop of the water table be- of displacement of the divide toward rea covered by the water of the dam I believe, be more rapid than it was natural conditions prior to the building dam, and because of the fact, the will reach the dam and make the loss ter dangerous. As a matter of fact, the cement rate of the divide, and conse- y of the drop in the water table, will eater, the smaller the distance between lleys concerned, and the greater the ence between the elevations of the tables in them.

reviewers believe that I was wrong. state that "1) Because leaching of car- rocks under natural conditions is slow, it can form caves only during eologic periods; and 2) the author for- existence of underwater hydraulics h a dam which continues draining ed waters near the shore of the arti- basin and averts 'displacement of the divide' in the direction mentioned by Ryzhikov" (p. 120). These "argu- " as we can see, are baseless. ly, I did not forget the existence of vater hydraulics (p. 124) and its sig- ce as a draining factor. This is cor- but how can they avert displacement subsurface water divide in an area d by water of the dam, frequently ing for tens of kilometers up-river he underwater hydraulics, if the inter- area is composed of pure, easily ble rocks and not of some kind of one, shale, or other impermeable i.e., if the interfluve area is a typi- ved area? Leaching of limestone is, rse, a slow process. But one should not forget that caves in limestone are not restricted to the area above the water table. They also occur at greater or even very great depths from the surface. We know from experience that large sinkholes with gentle slopes close to those of subsurface water tables emerge above limestone, the ground water from which has been pumped out through drill holes or shafts to a depth of 50 meters or more below the level of the original water table. The caving in takes places within two or three years after the start of pumping, but not more. Thus, a weakened drainage in one basin or an intensified drainage in the other will, under natural conditions, displace the subsurface water divide and move the water table downward at a rate close to that caused by pumping, even if there is no significant leaching of the rocks during this particular period; i.e., it acts because of caves formed previously. This proves that I was correct when I claimed that not all the examiners realize the principal sense and significance of engineering, geologic and hydrogeologic studies to be undertaken prior to hydrotechnical construction in caves areas.

7. In conclusion, the reviewers write: "disregarding the significance of solution is a major shortcoming of the book" (p. 120). This is not correct. In many places I emphasized that "solution is a very important feature of caving and determines its essence [underscoring mine], especially at early stages of its evolution" (p. 96). However, I do not consider solution as such, beyond its relation to the motion of dissolving waters, as the reviewers do, but as an integral feature of the evolution of the water table in the course of paleogeographic development, for this is the only way to understand the evolution of caves. Solution as such, no matter how it is studied and how successful the studies are, can never disclose the genesis of caves.

8. The reviewers believe that I confused the terms "erosion" and "denudation" and that the terms as used by the Americans do not mean the same things for which they are applied by European geologists, and consequently (?!) they think my discussion about the relationship between caving and erosion is a misunderstanding that supposedly led me to an incorrect conclusion that caving and erosion are very similar but at the same time differ greatly. It should be noticed, regardless of the confusion in the use of the terms (a study of this subject could lead to a special article), that I applied them in very definite senses, and the clar definitions given in my book by no means differ from the well-known views of other Soviet geologists. The development of a cave is, in my opinion, an analogue of erosion and prevails

in areas occupied by soluble rocks. Both erosion and caves develop in the course of competition between adjacent bases of erosion, controlled by epirogenic movements, and the motion of water divides toward the weaker pronounced drainage areas leads to the drop of the "dynamic" surfaces of both (surface of the earth in the case of erosion and water table in the case of caves) (p. 94 to 95).

In the areas of caves, the latter prevail, and not "everywhere a cooperative action of cave development and erosion" takes place, as the reviewers believe. This is the same kind of truth as the fact that in areas of caves, subsurface water dominates rather than surface water.

The above facts illustrate that the criticism by the reviewers is unreasonable and, in many cases, prejudicial. The correctness of my views concerning the nature of cav is evident, not only because of the partic features of caves and regularities in thei evolution, but also because of the proven facts in the course of hydrogeologic inves gations undertaken in cave areas during recent years.

The pattern of evolution of cave areas described in my book, will help Soviet a Chinese geologists -- in the languages o which the book was published -- to solve many problems of public economy better more completely (e.g., water supply, an measures to keep shafts dry), because t problems give rise to the necessity for cial studies of caved areas. The concept according to which a cave is an analogu erosion, opens a broad path to geologists their further study of caves and the rel geologic problems.

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